

Lab

Automatically-controlled process: *Questions 91 and 92*, **completed objectives due by the end of day 5, section 2**

Exam

Day 5 of next section

Specific objectives for the “mastery” exam:

- Electricity Review: Calculate voltages, currents, powers and/or resistances in a DC series-parallel circuit
 - Identify proper controller action (direct or reverse) for a given process
 - Predict the response of a single-loop control system to a component fault or process change
 - Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an “As-Found” table
 - Solve for a specified variable in an algebraic formula
 - Determine the possibility of suggested faults in a 4-20 mA loop circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
 - INST231 Review: Sketch proper wire connections for sourcing or sinking PLC I/O points
 - INST240 Review: Determine suitability of different level-measuring technologies for a given process fluid type
 - INST251 Review: Identify the graphed response of a controller as being either P, I, or D
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Recommended daily schedule

Day 1

Theory session topic: Feedback control

Questions 1 through 20; answer questions 1-8 in preparation for discussion (remainder for practice)

Day 2

Theory session topic: PID control

Questions 21 through 40; answer questions 21-28 in preparation for discussion (remainder for practice)

Day 3

Theory session topic: Loop controller function block programming

Questions 41 through 60; answer questions 41-45 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: DCS configuration

Questions 61 through 80; answer questions 61-68 in preparation for discussion (remainder for practice)

Feedback questions (*81 through 90*) are optional and may be submitted for review at the end of the day

How To . . .

Access the worksheets and textbook: go to the *Socratic Instrumentation* website located at <http://www.ibiblio.org/kuphaldt/socratic/sinst> to find worksheets for every 2nd-year course section organized by quarter, as well as both the latest “stable” and “development” versions of the *Lessons In Industrial Instrumentation* textbook. Download and save these documents to your computer.

Maximize your learning: come to school prepared each and every day – this means completing all your homework *before* class starts. Use every minute of class and lab time productively. Follow all the tips outlined in “Question 0” (in every course worksheet) as well as your instructor’s advice. Don’t ask anyone to help you solve a problem until you have made every reasonable effort to solve it on your own.

Identify upcoming assignments and deadlines: read the first page of each course worksheet.

Relate course days to calendar dates: reference the calendar spreadsheet file (`calendar.xlsx`), found on the BTC campus Y: network drive. A printed copy is posted in the Instrumentation classroom.

Locate industry documents assigned for reading: use the Instrumentation Reference provided by your instructor (on CD-ROM and on the BTC campus Y: network drive). There you will find a file named `00_index.OPEN.THIS.FILE.html` readable with any internet browser. Click on the “Quick-Start Links” to access assigned reading documents, organized per course, in the order they are assigned.

Study for the exams: Mastery exams assess specific skills critically important to your success, listed near the top of the front page of each course worksheet for your review. Familiarize yourself with this list and pay close attention when those topics appear in homework and practice problems. Proportional exams feature problems you haven’t seen before that are solvable using general principles learned throughout the current and previous courses, for which the only adequate preparation is independent problem-solving practice every day. Answer the “feedback questions” (practice exams) in each course section to hone your problem-solving skills, as these are similar in scope and complexity to proportional exams. Answer these feedback independently (i.e. no help from classmates) in order to most accurately assess your readiness.

Calculate course grades: download the “Course Grading Spreadsheet” (`grades_template.xlsx`) from the Socratic Instrumentation website, or from the BTC campus Y: network drive. Enter your quiz scores, test scores, lab scores, and attendance data into this Excel spreadsheet and it will calculate your course grade. You may compare your calculated grades against your instructors’ records at any time.

Identify courses to register for: read the “Sequence” page found in each worksheet.

Identify scholarship opportunities: check your BTC email in-box daily.

Identify job openings: regularly monitor job-search websites. Set up informational interviews at workplaces you are interested in. Participate in jobshadows and internships. Apply to jobs long before graduation, as some employers take *months* to respond! Check your BTC email account daily, because your instructor broadcast-emails job postings to all students as employers submit them to BTC.

Impress employers: sign the FERPA release form granting your instructors permission to share academic records, then make sure your performance is worth sharing. Document your project and problem-solving experiences for reference during interviews. Honor all your commitments.

Begin your career: participate in jobshadows and internships while in school to gain experience and references. Take the first Instrumentation job that pays the bills, and give that employer at least two years of good work to pay them back for the investment they have made in you. Employers look at delayed employment, as well as short employment spans, very negatively. Failure to pass a drug test is an immediate disqualifier, as is falsifying any information. Criminal records may also be a problem.

file howto

General Values and Expectations

Success in this career requires: professional integrity, resourcefulness, persistence, close attention to detail, and intellectual curiosity. Poor judgment spells disaster in this career, which is why employer background checks (including social media and criminal records) and drug testing are common. The good news is that character and clear thinking are malleable traits: unlike intelligence, these qualities can be acquired and improved with effort. *This is what you are in school to do* – increase your “human capital” which is the sum of all knowledge, skills, and traits valuable in the marketplace.

Mastery: You must master the fundamentals of your chosen profession. “Mastery” assessments challenge you to demonstrate 100% competence (with multiple opportunities to re-try). Failure to complete any mastery objective(s) by the deadline date caps your grade at a C–. Failure to complete by the end of the next school day results in a failing (F) grade.

Punctuality and Attendance: You are expected to arrive on time and be “on-task” all day just as you would for a job. Each student has 12 hours of “sick time” per quarter applicable to absences not verifiably employment-related, school-related, weather-related, or required by law. Each student must confer with the instructor to apply these hours to any missed time – this is not done automatically. Students may donate unused “sick time” to whomever they specifically choose. You must contact your instructor and lab team members immediately if you know you will be late or absent or must leave early. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

Time Management: You are expected to budget and prioritize your time, just as you will be on the job. You will need to reserve enough time outside of school to complete homework, and strategically apply your time during school hours toward limited resources (e.g. lab equipment). Frivolous activities (e.g. games, social networking, internet surfing) are unacceptable when work is unfinished. Trips to the cafeteria for food or coffee, smoke breaks, etc. must not interfere with team participation.

Independent Study: This career is marked by continuous technological development and ongoing change, which is why *self-directed learning* is ultimately more important to your future success than specific knowledge. To acquire and hone this skill, all second-year Instrumentation courses follow an “inverted” model where lecture is replaced by independent study, and class time is devoted to addressing your questions and demonstrating your learning. Most students require a *minimum* of 3 hours daily study time outside of school. Arriving unprepared (e.g. homework incomplete) is unprofessional and counter-productive. Question 0 of every worksheet lists practical study tips.

Independent Problem-Solving: The best instrument technicians are versatile problem-solvers. General problem-solving is arguably the most valuable skill you can possess for this career, and it can only be built through persistent effort. This is why you must take every reasonable measure to *solve problems on your own* before seeking help. It is okay to be perplexed by an assignment, but you are expected to apply problem-solving strategies given to you (see Question 0) and to precisely identify where you are confused so your instructor will be able to offer targeted help. Asking classmates to solve problems for you is folly – this includes having others break the problem down into simple steps. The point is to learn how to *think on your own*. When troubleshooting systems in lab you are expected to run diagnostic tests (e.g. using a multimeter instead of visually seeking circuit faults), as well as consult the equipment manual(s) before seeking help.

Initiative: No single habit predicts your success or failure in this career better than personal initiative, which is why your instructor will demand *you do for yourself rather than rely on others to do for you*. Examples include setting up and using your BTC email account to communicate with your instructor(s), consulting manuals for technical information before asking for help, regularly checking the course calendar and assignment deadlines, avoiding procrastination, fixing small problems before they become larger problems, etc. If you find your performance compromised by poor understanding of prior course subjects, re-read those textbook sections and use the practice materials made available to you on the Socratic Instrumentation website – don’t wait for anyone else to diagnose your need and offer help.

General Values and Expectations (continued)

Safety: You are expected to work safely in the lab just as you will be on the job. This includes wearing proper attire (safety glasses and closed-toed shoes in the lab at all times), implementing lock-out/tag-out procedures when working on circuits with exposed conductors over 30 volts, using ladders to access elevated locations, and correctly using all tools. If you need to use an unfamiliar tool, see the instructor for directions.

Orderliness: You are expected to keep your work area clean and orderly just as you will be on the job. This includes discarding trash and returning tools at the end of every lab session, and participating in all scheduled lab clean-up sessions. If you identify failed equipment in the lab, label that equipment with a detailed description of its symptoms.

Teamwork: You will work in instructor-assigned teams to complete lab assignments, just as you will work in teams to complete complex assignments on the job. As part of a team, you must keep your teammates informed of your whereabouts in the event you must step away from the lab or will be absent for *any* reason. Any student regularly compromising team performance through lack of participation, absence, tardiness, disrespect, or other disruptive behavior(s) will be removed from the team and required to complete all labwork individually for the remainder of the quarter. The same is true for students found relying on teammates to do their work for them.

Cooperation: The structure of these courses naturally lends itself to cooperation between students. Working together, students significantly impact each others' learning. You are expected to take this role seriously, offering real help when needed and not absolving classmates of their responsibility to think for themselves or to do their own work. Solving problems for classmates and/or explaining to them what they can easily read on their own is unacceptable because these actions circumvent learning. The best form of help you can give to your struggling classmates is to share with them your tips on independent learning and problem-solving, for example *asking questions* leading to solutions rather than simply providing solutions for them.

Grades: Employers prize trustworthy, hard working, knowledgeable, resourceful problem-solvers. The grade you receive in any course is but a *partial* measure of these traits. What matters most are the traits themselves, which is why your instructor maintains detailed student records (including individual exam scores, attendance, tardiness, and behavioral comments) and will share these records with employers if you have signed the FERPA release form. You are welcome to see your records at any time, and to compare calculated grades with your own records (i.e. the grade spreadsheet available to all students). You should expect employers to scrutinize your records on attendance and character, and also challenge you with technical questions when considering you for employment.

Representation: You are an ambassador for this program. Your actions, whether on tours, during a jobshadow or internship, or while employed, can open or shut doors of opportunity for other students. Most of the job opportunities open to you as a BTC graduate were earned by the good work of previous graduates, and as such you owe them a debt of gratitude. Future graduates depend on you to do the same.

Responsibility For Actions: If you lose or damage college property (e.g. lab equipment), you must find, repair, or help replace it. If you represent BTC poorly to employers (e.g. during a tour or an internship), you must make amends. The general rule here is this: *"If you break it, you fix it!"*

Non-negotiable terms: disciplinary action, up to and including immediate failure of a course, will result from academic dishonesty (e.g. cheating, plagiarism), willful safety violations, theft, harassment, intoxication, destruction of property, or willful disruption of the learning (work) environment. Such offenses are grounds for immediate termination in this career, and as such will not be tolerated here.

Course Syllabus

INSTRUCTOR CONTACT INFORMATION:

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DEPT/COURSE #: INST 262

CREDITS: 5 **Lecture Hours:** 22 **Lab Hours:** 70 **Work-based Hours:** 0

COURSE TITLE: Digital Control Systems

COURSE DESCRIPTION: This course teaches the basic principles of distributed instrumentation, including distributed control systems (DCS), FOUNDATION Fieldbus instruments, and wireless field instruments. **Pre/Corequisite course:** INST 260 (Data Acquisition Systems) **Prerequisite course:** MATH&141 (Precalculus 1) with a minimum grade of “C”

COURSE OUTCOMES: Commission, analyze, and efficiently diagnose instrumented systems incorporating networked control platforms (DCS, Fieldbus, wireless).

COURSE OUTCOME ASSESSMENT: DCS and Fieldbus system commissioning, analysis, and diagnosis outcomes are ensured by measuring student performance against mastery standards, as documented in the Student Performance Objectives. Failure to meet all mastery standards by the next scheduled exam day will result in a failing grade for the course.

STUDENT PERFORMANCE OBJECTIVES:

- Without references or notes, within a limited time (3 hours total for each exam session), independently perform the following tasks. Multiple re-tries are allowed on mastery (100% accuracy) objectives, each with a different set of problems:
 - Calculate voltages, currents, powers, and/or resistances in a DC series-parallel circuit, with 100% accuracy (mastery)
 - Calculate voltages and currents in an ideal AC transformer circuit, with 100% accuracy (mastery)
 - Identify proper controller action for a given process with 100% accuracy (mastery)
 - Predict the response of a single-loop control system to a component fault or process change, given pictorial and/or schematic illustrations, with 100% accuracy (mastery)
 - Determine proper AI block parameters to range a Fieldbus transmitter for a given application, with 100% accuracy (mastery)
 - Use decibels to calculate power gains and losses with 100% accuracy (mastery)
 - Calculate instrument input and output values given calibrated ranges, with 100% accuracy (mastery)
 - Identify specific instrument calibration errors (zero, span, linearity, hysteresis) from data in an “As-Found” table, with 100% accuracy (mastery)
 - Solve for specified variables in algebraic formulae, with 100% accuracy (mastery)
 - Determine the possibility of suggested faults in a simple circuit given measured values (voltage, current), a schematic diagram, and reported symptoms, with 100% accuracy (mastery)
 - Sketch proper power and signal connections between individual instruments to fulfill specified control system functions, given pictorial and/or schematic illustrations of those instruments
- In a team environment and with full access to references, notes, and instructor assistance, perform the following tasks:
 - Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems
 - Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all labwork
 - Construct and commission an automatically-controlled process using a PID controller
 - Generate an accurate loop diagram compliant with ISA standards documenting your team’s control system
 - Commission and decommission a WirelessHART instrument
 - Configure a digital indicator to poll instrument data via the Modbus protocol
- Independently perform the following tasks with 100% accuracy (mastery). Multiple re-tries are allowed with different specifications/conditions each time:
 - Connect an electromechanical interposing relay to energize a 120 VAC load using a DC control circuit, given components and criteria randomly selected by the instructor
 - Build a circuit and configure a HART-compatible DP transmitter to measure an applied pressure or vacuum according to criteria randomly selected by the instructor
 - Diagnose a random fault placed in another team’s control system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor’s direct presence

COURSE OUTLINE: A course calendar in electronic format (Excel spreadsheet) resides on the Y: network drive, and also in printed paper format in classroom DMC130, for convenient student access. This calendar is updated to reflect schedule changes resulting from employer recruiting visits, interviews, and other impromptu events. Course worksheets provide comprehensive lists of all course assignments and activities, with the first page outlining the schedule and sequencing of topics and assignment due dates. These worksheets are available in PDF format at <http://www.ibiblio.org/kuphaldt/socratic/sinst>

- INST262 Section 1 (Feedback control systems): 4 days theory and labwork
- INST262 Section 2 (DDC and DCS platforms): 4 days theory and labwork + 1 day for mastery/proportional Exams
- INST262 Section 3 (FOUNDATION Fieldbus): 4 days theory and labwork

- INST262 Section 4 (Wireless instrumentation): 4 days theory and labwork + 1 day for mastery/proportional Exams

METHODS OF INSTRUCTION: Course structure and methods are intentionally designed to develop critical-thinking and life-long learning abilities, continually placing the student in an active rather than a passive role.

- **Independent study:** daily worksheet questions specify *reading assignments*, *problems* to solve, and *experiments* to perform in preparation (before) classroom theory sessions. Open-note quizzes and work inspections ensure accountability for this essential preparatory work. The purpose of this is to convey information and basic concepts, so valuable class time isn't wasted transmitting bare facts, and also to foster the independent research ability necessary for self-directed learning in your career.
- **Classroom sessions:** a combination of *Socratic discussion*, short *lectures*, *small-group* problem-solving, and hands-on *demonstrations/experiments* review and illuminate concepts covered in the preparatory questions. The purpose of this is to develop problem-solving skills, strengthen conceptual understanding, and practice both quantitative and qualitative analysis techniques.
- **Lab activities:** an emphasis on constructing and documenting *working projects* (real instrumentation and control systems) to illuminate theoretical knowledge with practical contexts. Special projects off-campus or in different areas of campus (e.g. BTC's Fish Hatchery) are encouraged. Hands-on *troubleshooting exercises* build diagnostic skills.
- **Feedback questions:** sets of *practice problems* at the end of each course section challenge your knowledge and problem-solving ability in current as well as first year (Electronics) subjects. These are optional assignments, counting neither for nor against your grade. Their purpose is to provide you and your instructor with direct feedback on what you have learned.
- **Tours and guest speakers:** quarterly *tours* of local industry and *guest speakers* on technical topics add breadth and additional context to the learning experience.

STUDENT ASSIGNMENTS/REQUIREMENTS: All assignments for this course are thoroughly documented in the following course worksheets located at:

<http://www.ibiblio.org/kuphaldt/socratic/sinst/index.html>

- INST262_sec1.pdf
- INST262_sec2.pdf
- INST262_sec3.pdf
- INST262_sec4.pdf

EVALUATION AND GRADING STANDARDS: (out of 100% for the course grade)

- Completion of all mastery objectives = 50%
- Mastery exam scores (first attempt) = 10% (2 exams at 5% each)
- Proportional exam scores = 30% (2 exams at 15% each)
- Lab questions = 10% (2 question sets at 5% each)
- Quiz penalty = -1% per failed quiz
- Tardiness penalty = -1% per incident (1 “free” tardy per course)
- Attendance penalty = -1% per hour (12 hours “sick time” per quarter)
- Extra credit = +5% per project (assigned by instructor based on individual learning needs)

All grades are criterion-referenced (i.e. no grading on a “curve”)

100% ≥ A ≥ 95%	95% > A- ≥ 90%	
90% > B+ ≥ 86%	86% > B ≥ 83%	83% > B- ≥ 80%
80% > C+ ≥ 76%	76% > C ≥ 73%	73% > C- ≥ 70% (minimum passing course grade)
70% > D+ ≥ 66%	66% > D ≥ 63%	63% > D- ≥ 60% 60% > F

A graded “preparatory” quiz at the start of each classroom session gauges your independent learning prior to the session. A graded “summary” quiz at the conclusion of each classroom session gauges your comprehension of important concepts covered during that session. If absent during part or all of a classroom session, you may receive credit by passing comparable quizzes afterward or by having your preparatory work (reading outlines, work done answering questions) thoroughly reviewed prior to the absence.

Absence on a scheduled exam day will result in a 0% score for the proportional exam unless you provide documented evidence of an unavoidable emergency.

If you fail a mastery exam, you must re-take a different version of that mastery exam on a different day. Multiple re-tries are allowed, on a different version of the exam each re-try. There is no penalty levied on your course grade for re-taking mastery exams, but failure to successfully pass a mastery exam by the due date (i.e. by the date of the *next* exam in the course sequence) will result in a failing grade (F) for the course.

If any other “mastery” objectives are not completed by their specified deadlines, your overall grade for the course will be capped at 70% (C- grade), and you will have one more school day to complete the unfinished objectives. Failure to complete those mastery objectives by the end of that extra day (except in the case of documented, unavoidable emergencies) will result in a failing grade (F) for the course.

“Lab questions” are assessed by individual questioning, at any date after the respective lab objective (mastery) has been completed by your team. These questions serve to guide your completion of each lab exercise and confirm participation of each individual student. Grading is as follows: full credit for thorough, correct answers; half credit for partially correct answers; and zero credit for major conceptual errors. All lab questions must be answered by the due date of the lab exercise.

Extra credit opportunities exist for each course, and may be assigned to students upon request. The student and the instructor will first review the student’s performance on feedback questions, homework, exams, and any other relevant indicators in order to identify areas of conceptual or practical weakness. Then, both will work together to select an appropriate extra credit activity focusing on those identified weaknesses, for the purpose of strengthening the student’s competence. A due date will be assigned (typically two weeks following the request), which must be honored in order for any credit to be earned from the activity. Extra credit may be denied at the instructor’s discretion if the student has not invested the necessary preparatory effort to perform well (e.g. lack of preparation for daily class sessions, poor attendance, no feedback questions submitted, etc.).

REQUIRED STUDENT SUPPLIES AND MATERIALS:

- Course worksheets available for download in PDF format
- *Lessons in Industrial Instrumentation* textbook, available for download in PDF format
→ Access worksheets and book at: <http://www.ibiblio.org/kuphaldt/socratic/sinst>
- Spiral-bound notebook for reading annotation, homework documentation, and note-taking.
- Instrumentation reference CD-ROM (free, from instructor). This disk contains many tutorials and datasheets in PDF format to supplement your textbook(s).
- Tool kit (see detailed list)
- Simple scientific calculator (non-programmable, non-graphing, no unit conversions, no numeration system conversions), TI-30Xa or TI-30XIIS recommended

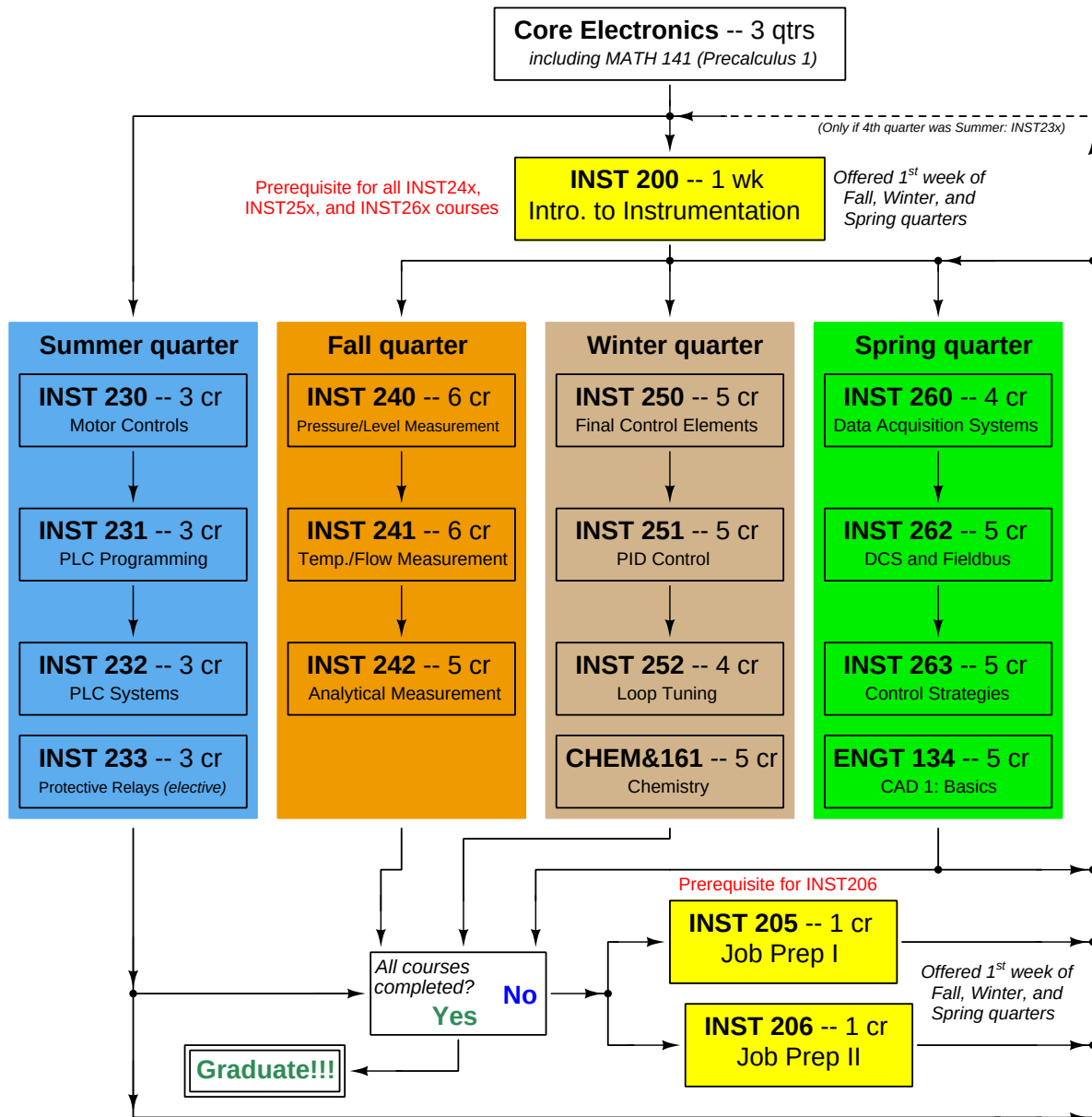
ADDITIONAL INSTRUCTIONAL RESOURCES:

- The BTC Library hosts a substantial collection of textbooks and references on the subject of Instrumentation, as well as links in its online catalog to free Instrumentation e-book resources available on the Internet.
- “BTCInstrumentation” channel on YouTube (<http://www.youtube.com/BTCInstrumentation>), hosts a variety of short video tutorials and demonstrations on instrumentation.
- ISA Student Section at BTC meets regularly to set up industry tours, raise funds for scholarships, and serve as a general resource for Instrumentation students. Membership in the ISA is \$10 per year, payable to the national ISA organization. Membership includes a complementary subscription to *InTech* magazine.
- ISA website (<http://www.isa.org>) provides all of its standards in electronic format, many of which are freely available to ISA members.
- *Normal Accidents*, by Charles Perrow. ISBN-10: 0691004129 ; ISBN-13: 978-0691004129.
- *Instrument Engineer’s Handbook, Volume 2: Process Control and Optimization*, edited by Béla Lipták, published by CRC Press. 4th edition ISBN-10: 0849310814 ; ISBN-13: 978-0849310812.
- *Purdy’s Instrument Handbook*, by Ralph Dewey. ISBN-10: 1-880215-26-8. A pocket-sized field reference on basic measurement and control.
- *Cad Standard* (CadStd) or similar AutoCAD-like drafting software (useful for sketching loop and wiring diagrams). Cad Standard is a simplified clone of AutoCAD, and is freely available at: <http://www.cadstd.com>

CAMPUS EMERGENCIES: If an emergency arises, your instructor may inform you of actions to follow. You are responsible for knowing emergency evacuation routes from your classroom. If police or university officials order you to evacuate, do so calmly and assist those needing help. You may receive emergency information alerts via the building enunciation system, text message, email, or BTC’s webpage (<http://www.btc.ctc.edu>), Facebook or Twitter. Refer to the emergency flipchart in the lab room (located on the main control panel) for more information on specific types of emergencies.

ACCOMMODATIONS: If you think you could benefit from classroom accommodations for a disability (physical, mental, emotional, or learning), please contact our Accessibility Resources office. Call (360)-752-8345, email ar@btc.ctc.edu, or stop by the AR Office in the Admissions and Student Resource Center (ASRC), Room 106, College Services Building

Sequence of second-year Instrumentation courses



The particular sequence of courses you take during the second year depends on when you complete all first-year courses and enter the second year. Since students enter the second year of Instrumentation at four different times (beginnings of Summer, Fall, Winter, and Spring quarters), the particular course sequence for any student will likely be different from the course sequence of classmates.

Some second-year courses are only offered in particular quarters with those quarters not having to be in sequence, while others are offered three out of the four quarters and must be taken in sequence. The following layout shows four typical course sequences for second-year Instrumentation students, depending on when they first enter the second year of the program:

Possible course schedules depending on date of entry into 2nd year



file sequence

General tool and supply list

Wrenches

- Combination (box- and open-end) wrench set, 1/4" to 3/4" – *the most important wrench sizes are 7/16", 1/2", 9/16", and 5/8"; get these immediately!*
- Adjustable wrench, 6" handle (sometimes called "Crescent" wrench)
- Hex wrench ("Allen" wrench) set, fractional – 1/16" to 3/8"
- *Optional:* Hex wrench ("Allen" wrench) set, metric – 1.5 mm to 10 mm
- *Optional:* Miniature combination wrench set, 3/32" to 1/4" (sometimes called an "ignition wrench" set)

Note: *when turning any threaded fastener, one should choose a tool engaging the maximum amount of surface area on the fastener's head in order to reduce stress on that fastener. (e.g. Using box-end wrenches instead of adjustable wrenches; using the proper size and type of screwdriver; never using any tool that mars the fastener such as pliers or vise-grips unless absolutely necessary.)*

Pliers

- Needle-nose pliers
- Tongue-and-groove pliers (sometimes called "Channel-lock" pliers)
- Diagonal wire cutters (sometimes called "dikes")

Screwdrivers

- Slotted, 1/8" and 1/4" shaft
- Phillips, #1 and #2
- Jeweler's screwdriver set
- *Optional:* Magnetic multi-bit screwdriver (e.g. Klein Tools model 70035)

Electrical

- Multimeter, Fluke model 87-IV or better
- Alligator-clip jumper wires
- Soldering iron (10 to 40 watt) and rosin-core solder
- Resistor, potentiometer, diode assortments (from first-year lab kits)
- Package of insulated compression-style fork terminals (14 to 18 AWG wire size, #10 stud size)
- Wire strippers/terminal crimpers for 10 AWG to 18 AWG wire and insulated terminals
- *Optional:* ratcheting terminal crimp tool (e.g. Paladin 1305, Ferrules Direct FDT10011, or equivalent)

Safety

- Safety glasses or goggles (available at BTC bookstore)
- Earplugs (available at BTC bookstore)

Miscellaneous

- Simple scientific calculator (non-programmable, non-graphing, no conversions), TI-30Xa or TI-30XIIS recommended. Required for some exams!
- Masking tape (for making temporary labels)
- Permanent marker pen
- Teflon pipe tape
- Utility knife
- Tape measure, 12 feet minimum
- Flashlight

An inexpensive source of tools is your local pawn shop. Look for tools with unlimited lifetime guarantees (e.g. *Sears* "Craftsman" brand). Check for BTC student discounts as well!

file tools

Methods of instruction

This course develops self-instructional and diagnostic skills by placing students in situations where they are required to research and think independently. In all portions of the curriculum, the goal is to avoid a passive learning environment, favoring instead *active engagement* of the learner through reading, reflection, problem-solving, and experimental activities. The curriculum may be roughly divided into two portions: *theory* and *practical*.

Theory

In the theory portion of each course, students independently research subjects *prior* to entering the classroom for discussion. This means working through all the day's assigned questions as completely as possible. This usually requires a fair amount of technical reading, and may also require setting up and running simple experiments. At the start of the classroom session, the instructor will check each student's preparation with a quiz. Students then spend the rest of the classroom time working in groups and directly with the instructor to *thoroughly* answer all questions assigned for that day, articulate problem-solving strategies, and to approach the questions from multiple perspectives. To put it simply: fact-gathering happens outside of class and is the individual responsibility of each student, so that class time may be devoted to the more complex tasks of critical thinking and problem solving where the instructor's attention is best applied.

Classroom theory sessions usually begin with either a brief Q&A discussion or with a "Virtual Troubleshooting" session where the instructor shows one of the day's diagnostic question diagrams while students propose diagnostic tests and the instructor tells those students what the test results would be given some imagined ("virtual") fault scenario, writing the test results on the board where all can see. The students then attempt to identify the nature and location of the fault, based on the test results.

Each student is free to leave the classroom when they have completely worked through all problems and have answered a "summary" quiz designed to gauge their learning during the theory session. If a student finishes ahead of time, they are free to leave, or may help tutor classmates who need extra help.

The express goal of this "inverted classroom" teaching methodology is to help each student cultivate critical-thinking and problem-solving skills, and to sharpen their abilities as independent learners. While this approach may be very new to you, it is more realistic and beneficial to the type of work done in instrumentation, where critical thinking, problem-solving, and independent learning are "must-have" skills.

Lab

In the lab portion of each course, students work in teams to install, configure, document, calibrate, and troubleshoot working instrument loop systems. Each lab exercise focuses on a different type of instrument, with a eight-day period typically allotted for completion. An ordinary lab session might look like this:

- (1) Start of practical (lab) session: announcements and planning
 - (a) The instructor makes general announcements to all students
 - (b) The instructor works with team to plan that day's goals, making sure each team member has a clear idea of what they should accomplish
- (2) Teams work on lab unit completion according to recommended schedule:
 - (First day) Select and bench-test instrument(s)
 - (One day) Connect instrument(s) into a complete loop
 - (One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
 - (One or two days) Each team member calibrates/configures the instrument(s)
 - (Remaining days, up to last) Each team member troubleshoots the instrument loop
- (3) End of practical (lab) session: debriefing where each team reports on their work to the whole class

Troubleshooting assessments must meet the following guidelines:

- Troubleshooting must be performed *on a system the student did not build themselves*. This forces students to rely on another team's documentation rather than their own memory of how the system was built.
- Each student must individually demonstrate proper troubleshooting technique.
- Simply finding the fault is not good enough. Each student must consistently demonstrate sound reasoning while troubleshooting.
- If a student fails to properly diagnose the system fault, they must attempt (as many times as necessary) with different scenarios until they do, reviewing any mistakes with the instructor after each failed attempt.

Distance delivery methods

Sometimes the demands of life prevent students from attending college 6 hours per day. In such cases, there exist alternatives to the normal 8:00 AM to 3:00 PM class/lab schedule, allowing students to complete coursework in non-traditional ways, at a “distance” from the college campus proper.

For such “distance” students, the same worksheets, lab activities, exams, and academic standards still apply. Instead of working in small groups and in teams to complete theory and lab sections, though, students participating in an alternative fashion must do all the work themselves. Participation via teleconferencing, video- or audio-recorded small-group sessions, and such is encouraged and supported.

There is no recording of hours attended or tardiness for students participating in this manner. The pace of the course is likewise determined by the “distance” student. Experience has shown that it is a benefit for “distance” students to maintain the same pace as their on-campus classmates whenever possible.

In lieu of small-group activities and class discussions, comprehension of the theory portion of each course will be ensured by completing and submitting detailed answers for *all* worksheet questions, not just passing daily quizzes as is the standard for conventional students. The instructor will discuss any incomplete and/or incorrect worksheet answers with the student, and ask that those questions be re-answered by the student to correct any misunderstandings before moving on.

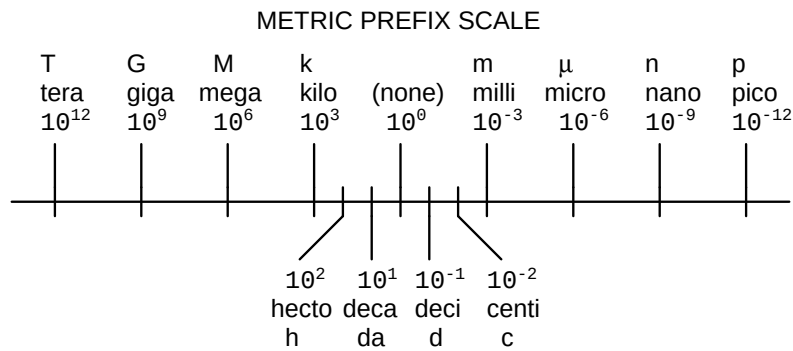
Labwork is perhaps the most difficult portion of the curriculum for a “distance” student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. “Distance” students must find a way to complete the required lab activities, either by arranging time in the school lab facility and/or completing activities on equivalent equipment outside of school (e.g. at their place of employment, if applicable). Labwork completed outside of school must be validated by a supervisor and/or documented via photograph or videorecording.

Conventional students may opt to switch to “distance” mode at any time. This has proven to be a benefit to students whose lives are disrupted by catastrophic events. Likewise, “distance” students may switch back to conventional mode if and when their schedules permit. Although the existence of alternative modes of student participation is a great benefit for students with challenging schedules, it requires a greater investment of time and a greater level of self-discipline than the traditional mode where the student attends school for 6 hours every day. No student should consider the “distance” mode of learning a way to have more free time to themselves, because they will actually spend more time engaged in the coursework than if they attend school on a regular schedule. It exists merely for the sake of those who cannot attend during regular school hours, as an alternative to course withdrawal.

Metric prefixes and conversion constants

- **Metric prefixes**

- Yotta = 10^{24} Symbol: Y
- Zeta = 10^{21} Symbol: Z
- Exa = 10^{18} Symbol: E
- Peta = 10^{15} Symbol: P
- Tera = 10^{12} Symbol: T
- Giga = 10^9 Symbol: G
- Mega = 10^6 Symbol: M
- Kilo = 10^3 Symbol: k
- Hecto = 10^2 Symbol: h
- Deca = 10^1 Symbol: da
- Deci = 10^{-1} Symbol: d
- Centi = 10^{-2} Symbol: c
- Milli = 10^{-3} Symbol: m
- Micro = 10^{-6} Symbol: μ
- Nano = 10^{-9} Symbol: n
- Pico = 10^{-12} Symbol: p
- Femto = 10^{-15} Symbol: f
- Atto = 10^{-18} Symbol: a
- Zepto = 10^{-21} Symbol: z
- Yocto = 10^{-24} Symbol: y



- **Conversion formulae for temperature**

- $^{\circ}\text{F} = (^{\circ}\text{C})(9/5) + 32$
- $^{\circ}\text{C} = (^{\circ}\text{F} - 32)(5/9)$
- $^{\circ}\text{R} = ^{\circ}\text{F} + 459.67$
- $\text{K} = ^{\circ}\text{C} + 273.15$

Conversion equivalencies for distance

- 1 inch (in) = 2.540000 centimeter (cm)
- 1 foot (ft) = 12 inches (in)
- 1 yard (yd) = 3 feet (ft)
- 1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

1 gallon (gal) = 231.0 cubic inches (in³) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.)
= 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm³)

Conversion equivalencies for velocity

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934
kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

Conversion equivalencies for mass

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

Conversion equivalencies for force

1 pound-force (lbf) = 4.44822 newton (N)

Conversion equivalencies for area

1 acre = 43560 square feet (ft²) = 4840 square yards (yd²) = 4046.86 square meters (m²)

Conversion equivalencies for common pressure units (either all gauge or all absolute)

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in.
W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

Conversion equivalencies for absolute pressure units (only)

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute
(kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

Conversion equivalencies for energy or work

1 british thermal unit (Btu – “International Table”) = 251.996 calories (cal – “International Table”)
= 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506 x 10¹⁰
ergs (erg) = 778.169 foot-pound-force (ft-lbf)

Conversion equivalencies for power

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour
(Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

Acceleration of gravity (free fall), Earth standard

9.806650 meters per second per second (m/s²) = 32.1740 feet per second per second (ft/s²)

Physical constants

Speed of light in a vacuum (c) = 2.9979×10^8 meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number (N_A) = 6.022×10^{23} per mole (mol^{-1})

Electronic charge (e) = 1.602×10^{-19} Coulomb (C)

Boltzmann's constant (k) = 1.38×10^{-23} Joules per Kelvin (J/K)

Stefan-Boltzmann constant (σ) = 5.67×10^{-8} Watts per square meter-Kelvin⁴ ($\text{W}/\text{m}^2 \cdot \text{K}^4$)

Molar gas constant (R) = 8.314 Joules per mole-Kelvin (J/mol-K)

Properties of Water

Freezing point at sea level = $32^\circ\text{F} = 0^\circ\text{C}$

Boiling point at sea level = $212^\circ\text{F} = 100^\circ\text{C}$

Density of water at 4°C = $1000 \text{ kg}/\text{m}^3 = 1 \text{ g}/\text{cm}^3 = 1 \text{ kg}/\text{liter} = 62.428 \text{ lb}/\text{ft}^3 = 1.94 \text{ slugs}/\text{ft}^3$

Specific heat of water at 14°C = $1.00002 \text{ calories}/\text{g} \cdot ^\circ\text{C} = 1 \text{ BTU}/\text{lb} \cdot ^\circ\text{F} = 4.1869 \text{ Joules}/\text{g} \cdot ^\circ\text{C}$

Specific heat of ice $\approx 0.5 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Specific heat of steam $\approx 0.48 \text{ calories}/\text{g} \cdot ^\circ\text{C}$

Absolute viscosity of water at 20°C = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa·s)

Surface tension of water (in contact with air) at 18°C = 73.05 dynes/cm

pH of pure water at 25°C = 7.0 (*pH scale = 0 to 14*)

Properties of Dry Air at sea level

Density of dry air at 20°C and 760 torr = $1.204 \text{ mg}/\text{cm}^3 = 1.204 \text{ kg}/\text{m}^3 = 0.075 \text{ lb}/\text{ft}^3 = 0.00235 \text{ slugs}/\text{ft}^3$

Absolute viscosity of dry air at 20°C and 760 torr = 0.018 centipoise (cp) = 1.8×10^{-5} Pascal-seconds (Pa·s)

file conversion_constants

How to get the most out of academic reading:

- Articulate your thoughts as you read (i.e. “have a conversation” with the author). This will develop *metacognition*: active supervision of your own thoughts. Write your thoughts as you read, noting points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications. These notes should also document important math formulae, explaining in your own words what each formula means and the proper units of measurement used.
- Outline, don’t highlight! Writing your own summary or outline is a far more effective way to comprehend a text than simply underlining and highlighting key words. A suggested ratio is one sentence of your own thoughts per paragraph of text read. Note points of disagreement or confusion to explore later.
- Work through all mathematical exercises shown within the text, to ensure you understand all the steps.
- Imagine explaining concepts you’ve just learned to someone else. Teaching forces you to distill concepts to their essence, thereby clarifying those concepts, revealing assumptions, and exposing misconceptions. Your goal is to create the simplest explanation that is still technically accurate.
- Write your own questions based on what you read, as though you are a teacher preparing to test students’ comprehension of the subject matter.

How to effectively problem-solve and troubleshoot:

- Study principles, not procedures. Don’t be satisfied with merely knowing how to compute solutions – learn *why* those solutions work. In mathematical problem-solving this means being able to identify the practical meaning (and units of measurement) of every intermediate calculation. In other words, *every step of your solution should make logical sense.*
- Sketch a diagram to help visualize the problem. When building a real system, always prototype it on paper and analyze its function *before* constructing it.
- Identify what it is you need to solve, identify all relevant data, identify all units of measurement, identify any general principles or formulae linking the given information to the solution, and then identify any “missing pieces” to a solution. Annotate all diagrams with this data.
- Perform “thought experiments” to explore the effects of different conditions for theoretical problems. When troubleshooting real systems, perform *diagnostic tests* rather than visually inspecting for faults.
- Simplify the problem and solve that simplified problem to identify strategies applicable to the original problem (e.g. change quantitative to qualitative, or visa-versa; substitute easier numerical values; eliminate confusing details; add details to eliminate unknowns; consider simple limiting cases; apply an analogy). Often you can add or remove components in a malfunctioning system to simplify it as well and better identify the nature and location of the problem.
- Work “backward” from a hypothetical solution to a new set of given conditions.

How to create more time for study:

- Kill your television and video games. Seriously – these are incredible wastes of time. Eliminate distractions (e.g. cell phone, internet, socializing) in your place and time of study.
- Use your “in between” time productively. Don’t leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin studying the next day’s material.

Above all, cultivate persistence. Persistent effort is necessary to master anything non-trivial. The keys to persistence are (1) having the desire to achieve that mastery, and (2) realizing challenges are normal and not an indication of something gone wrong. A common error is to equate *easy* with *effective*: students often believe learning should be easy if everything is done right. The truth is that mastery never comes easy!

file question0

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Questions

Question 1

Read and outline the “Basic Feedback Control Principles” section of the “Closed-Loop Control” chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

[file i04254](#)

Question 2

Read and outline the “On/Off Control” section of the “Closed-Loop Control” chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

[file i04255](#)

Question 3

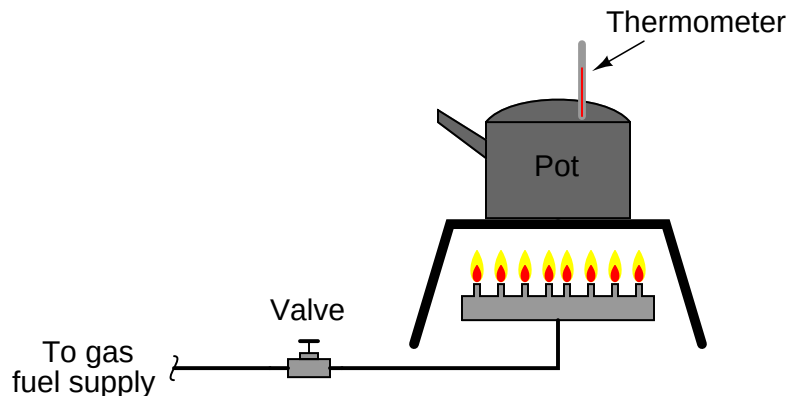
Read and outline the “Proportional-Only Control” section of the “Closed-Loop Control” chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

[file i04256](#)

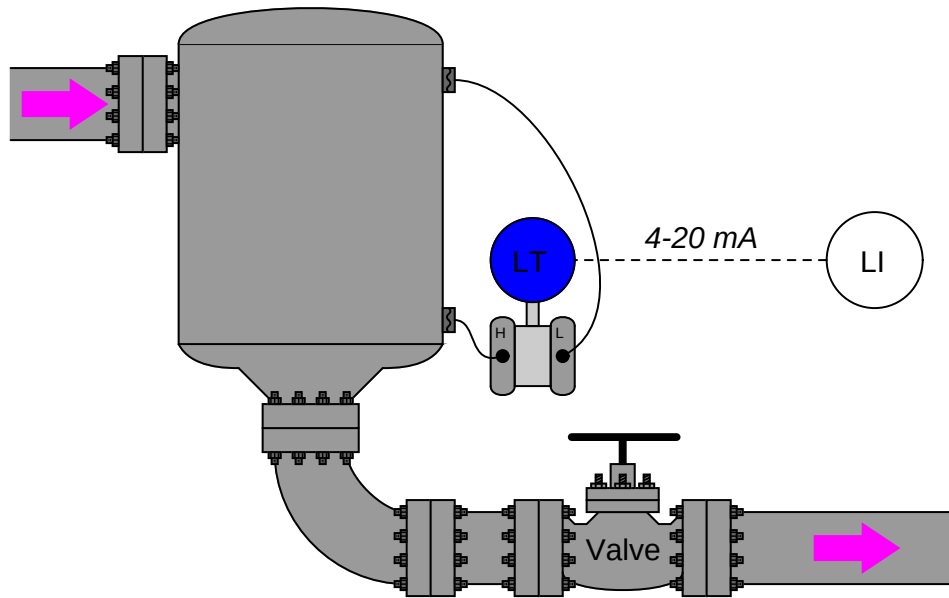
Question 4

In any automated (controlled) system, there is a *process variable*, a *setpoint*, and a *manipulated variable*. There is also something called a *load*, which influences how well the control system is able to maintain setpoint. Provide a general description for a “load,” and then identify the load(s) in each of the following manually-controlled processes:

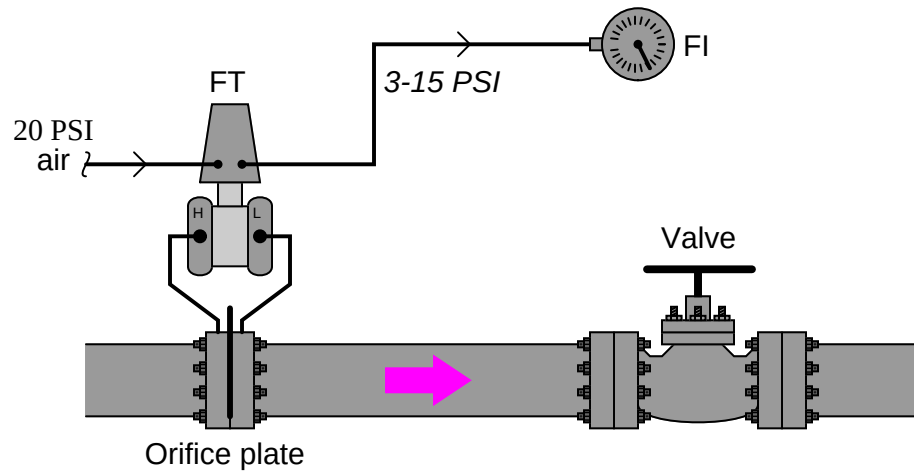
Example 1: Temperature control application



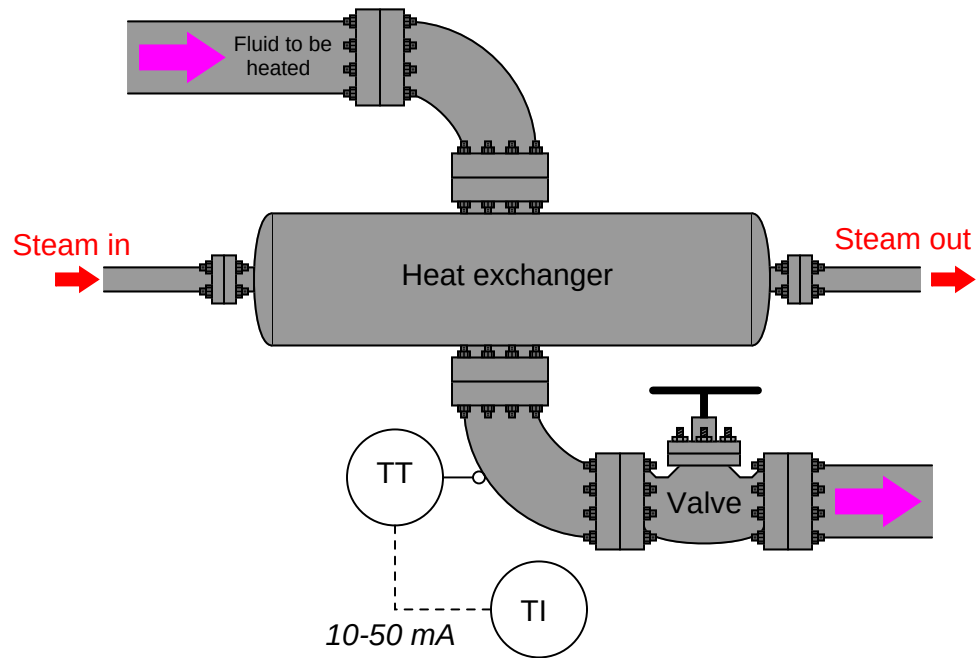
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



Suggestions for Socratic discussion

- Explain why ambient air temperature is considered a *load* to process example #4, but the insulation thickness on the heat exchanger is not.

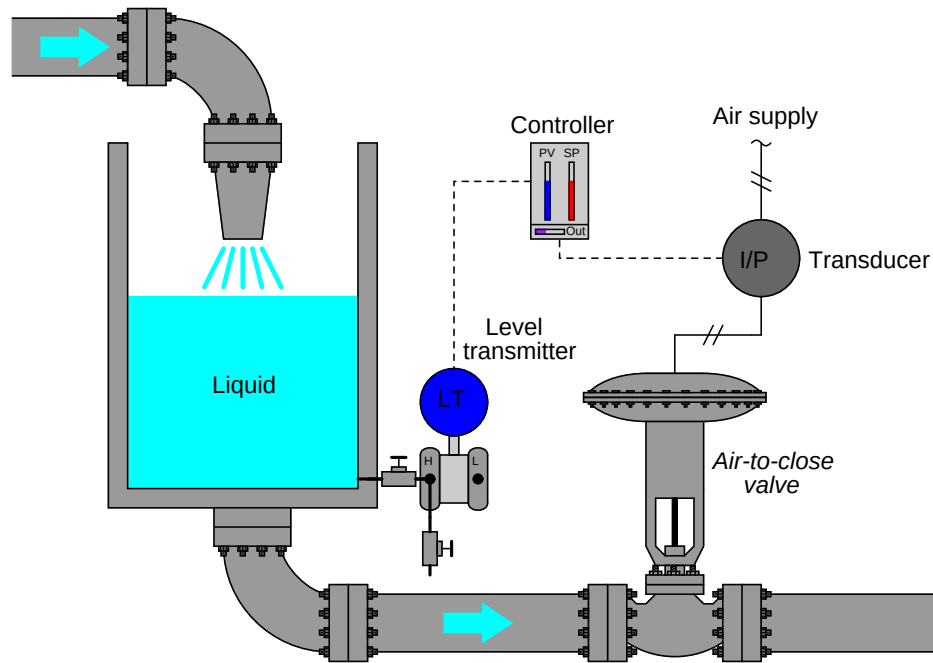
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Question 5

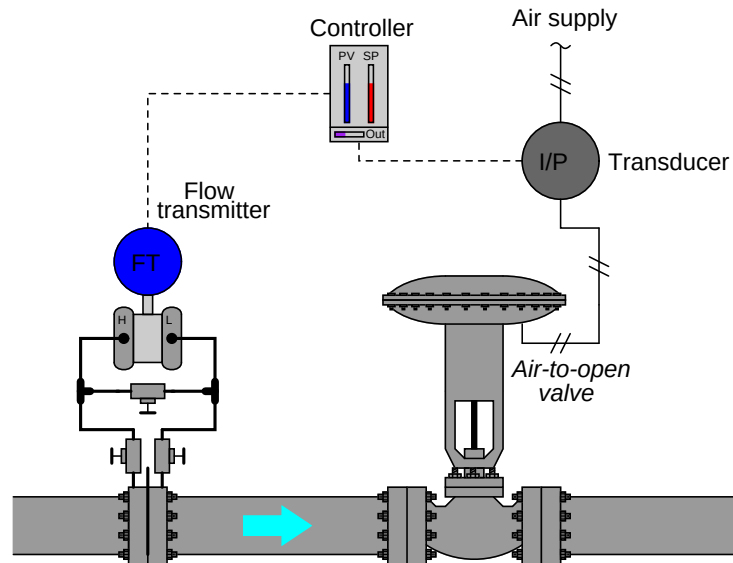
In each of these process control examples, the transmitter produces an increasing signal for an increase in process measurement (level, pressure, temperature, etc.), and the I/P transducer produces an increasing air pressure signal out for an increasing current signal in.

Your task is to determine the proper action for the process controller, either *direct-acting* or *reverse-acting*. Remember, a direct-acting controller produces an increasing output signal with an increasing process variable input. A reverse-acting controller produces a decreasing output signal for an increasing process variable input. It is essential for stability that the controller have the correct direction of action!

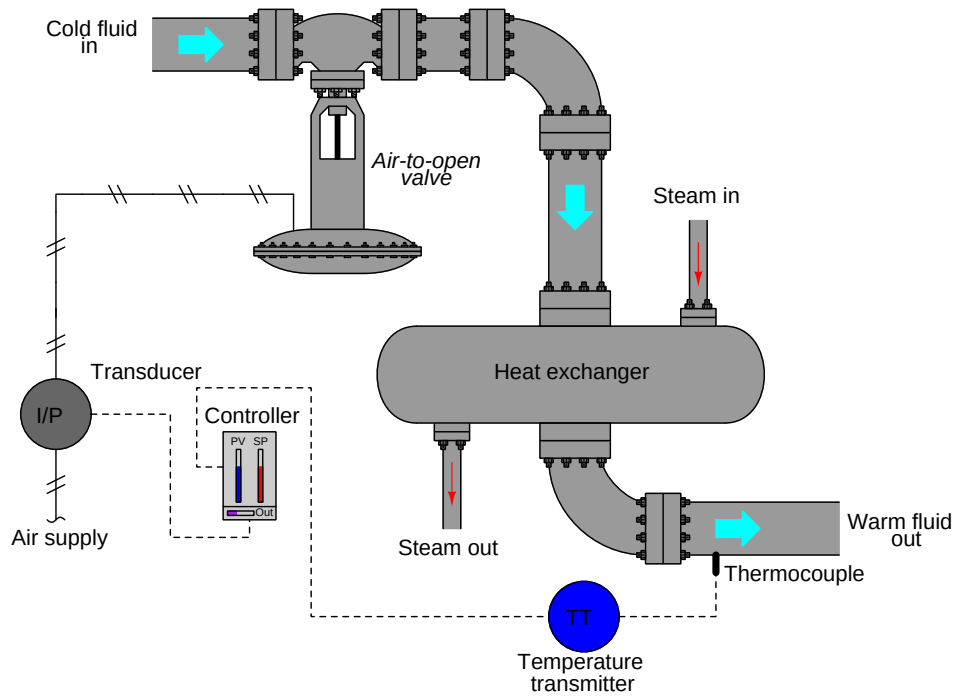
Example 1:



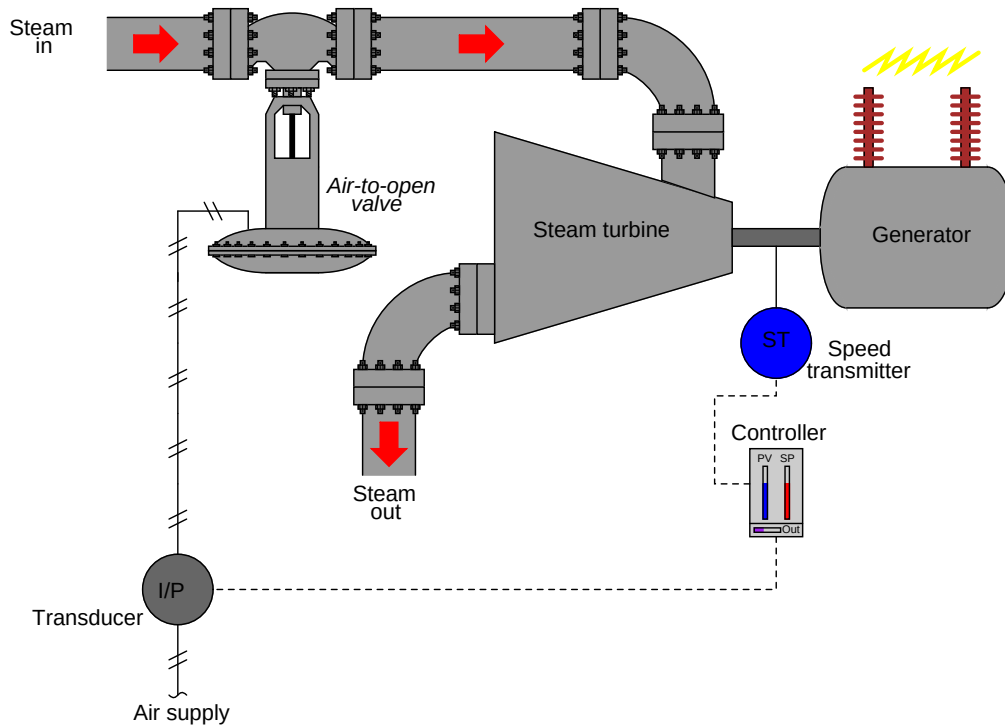
Example 2:



Example 3:

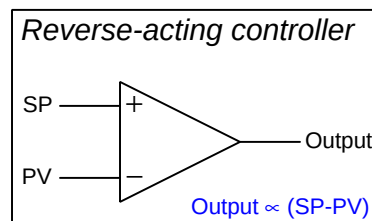
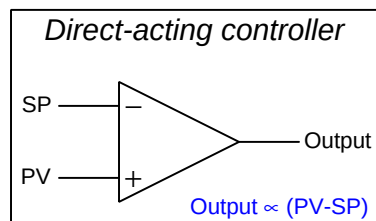


Example 4:

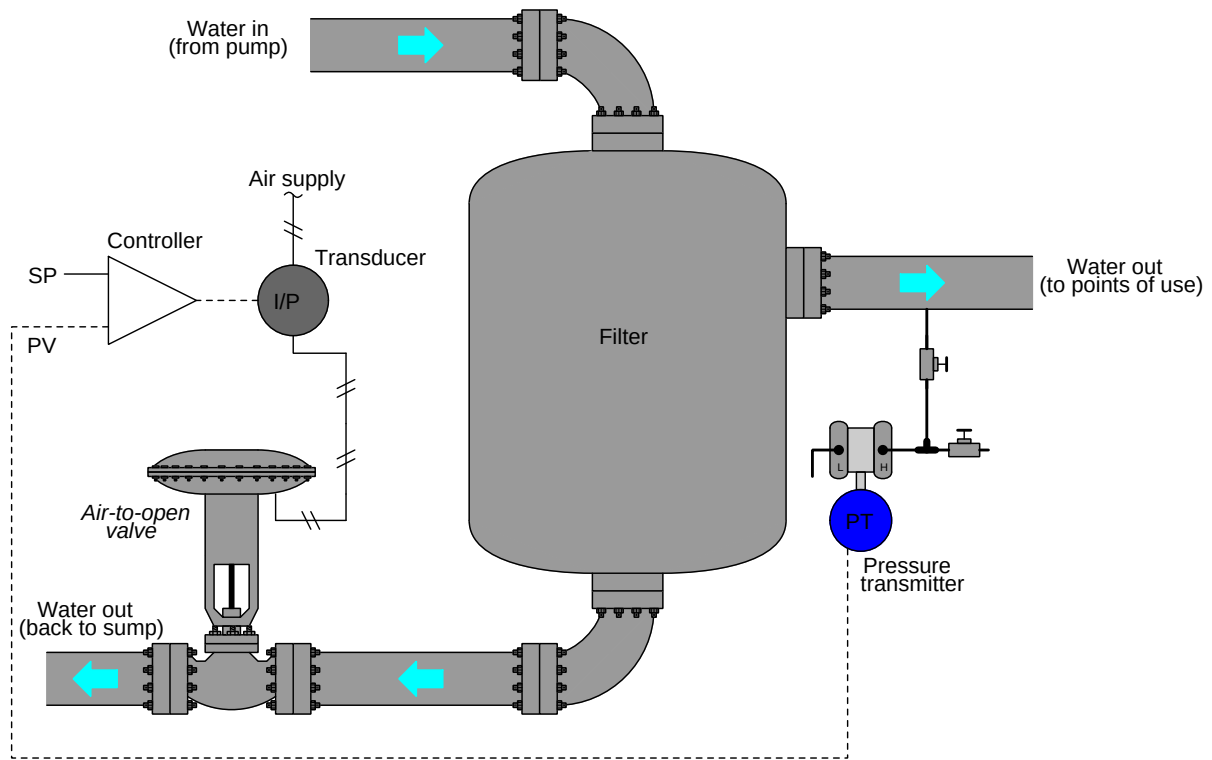


A concept familiar to students of electronics is the *differential amplifier*, a device built to compare two input signals and generate an output signal proportional to that comparison. The most common form of differential amplifier is the so-called *operational amplifier* or “opamp”, drawn as a triangle with two inputs labeled “+” and “-” to show the relative influence of each input signal on the output. A process controller may be thought of as a kind of differential amplifier, sensing the difference between two input signals (the process variable and the setpoint) and generating an output signal proportional to the difference between PV and SP to drive a final control element.

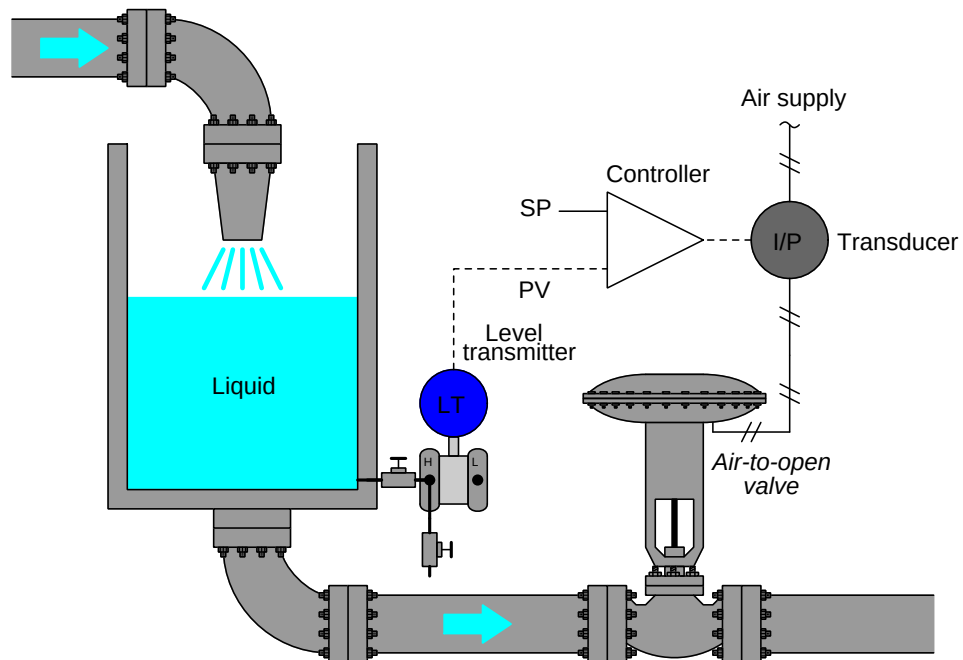
The following process control examples replace the controller symbol with an amplifier symbol. Your task is to figure out appropriate labels for the amplifier’s input terminals (e.g. “+” and “-”). Remember that a controller is defined as being “direct-acting” if an increase in PV causes an increase in output and “reverse-acting” if an increase in PV causes a decrease in output. Following opamp labeling, this means the PV input of a direct-acting controller should bear a “+” mark while the PV input of a reverse-acting controller should bear a “-” mark.



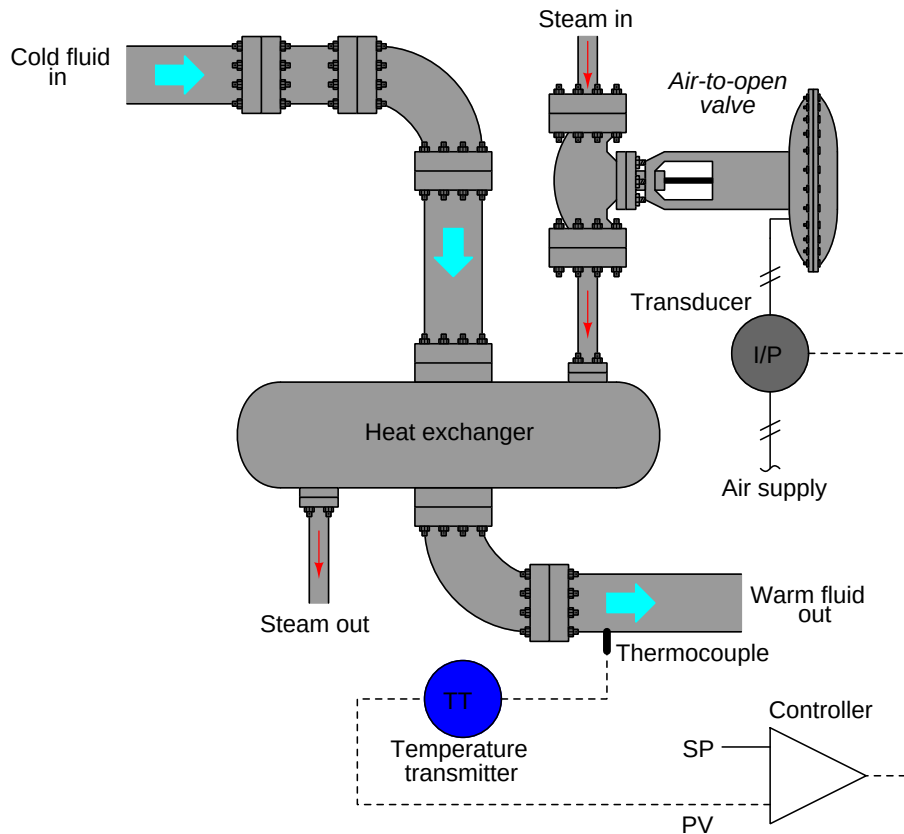
Example 5: Label the PV & SP amplifier inputs for the correct controller action



Example 6: Label the PV & SP amplifier inputs for the correct controller action



Example 7: Label the PV & SP amplifier inputs for the correct controller action



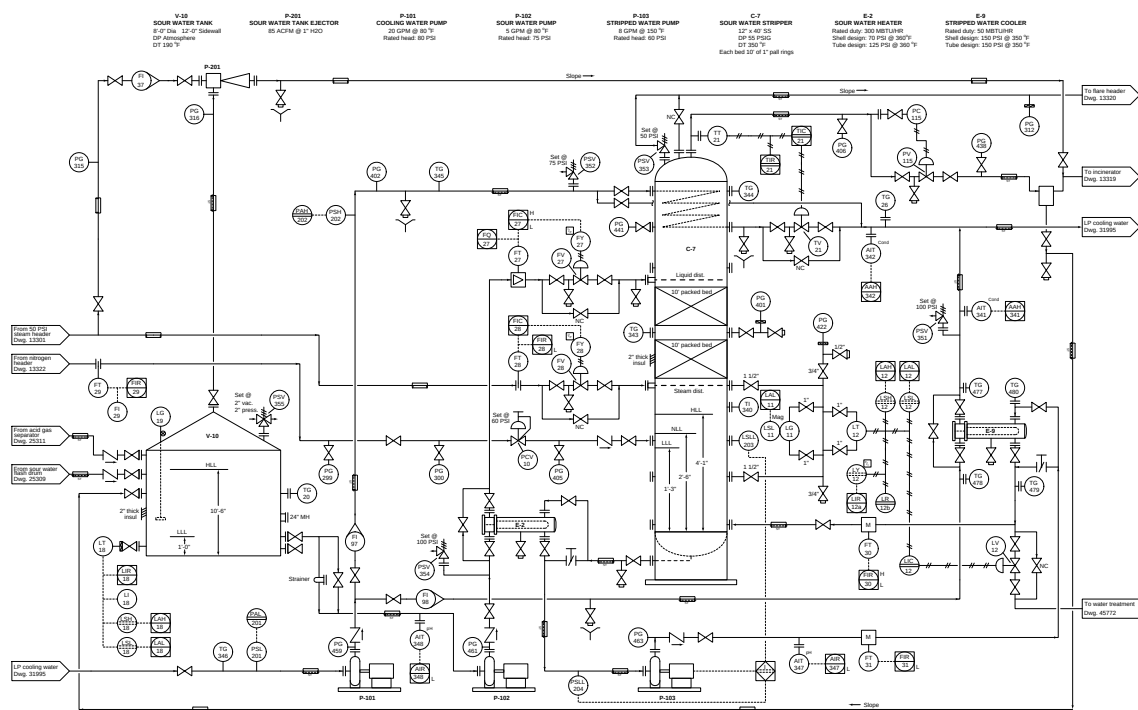
Suggestions for Socratic discussion

- As always, what is more important than arriving at the correct answer(s) is to develop a clear and logical *reason* for your correct answers. Explain the problem-solving technique(s) you used to determine correct controller action in each of these process control examples.
- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful “thought experiment” for any of these process control loops, and how the results of that thought experiment are helpful to answering the question.
- Explain how to reliably identify the process variable (PV) in any controlled process presented to you.
- Explain how to reliably identify the manipulated variable (MV) in any controlled process presented to you.
- Identify and explain the deleterious effect(s) caused by a process controller configured with the wrong action.
- Identify an instrument mis-calibration or mis-configuration that could cause the process variable to settle at a greater value than it should be, assuming all other components in the system are functioning properly.
- Once you have identified the proper controller action for any given process example, identify something that could be altered about the process to require the *other* control action.

[file i00788](#)

Question 6

In this process, hot steam is used to “strip” volatile sulfur compounds from process water, inside a vessel called a *stripping tower*. A flow control system (loop #28) regulates the amount of stripping steam admitted to the tower:



Suppose the last instrument technician to calibrate the steam flow transmitter (FT-28) made a mistake, and the transmitter consistently reads 1.2 pound per minute more steam flow than there actually is going through the pipe. For example, if the actual steam flow is 6.9 pounds per minute, the transmitter outputs a current signal corresponding to 8.1 pounds per minute.

Describe in detail the effect this mis-calibration will have on the performance of the steam flow control system.

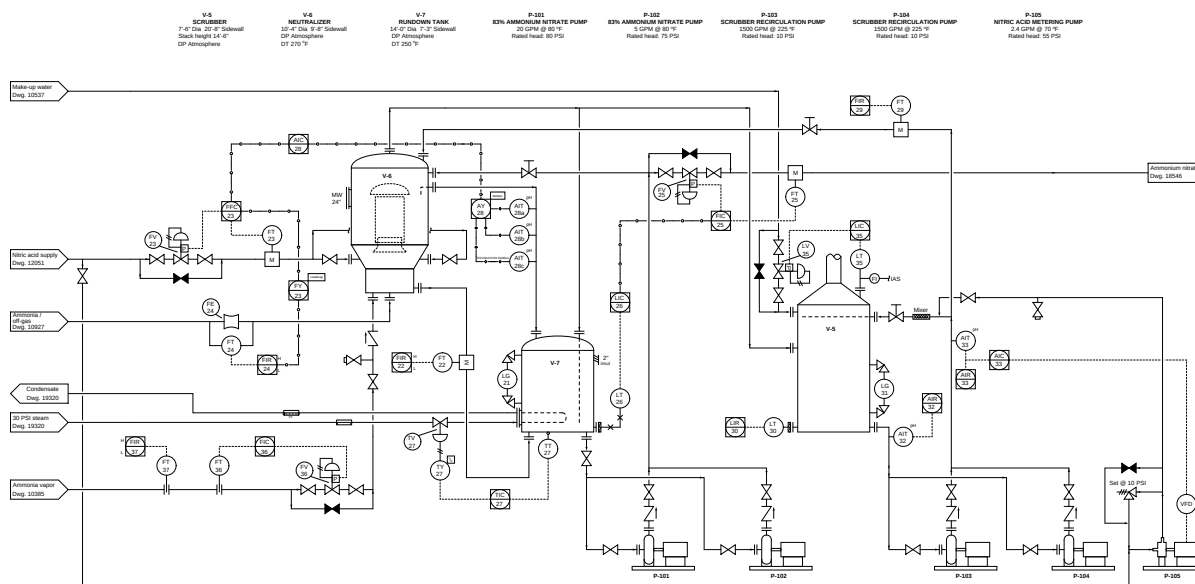
Suggestions for Socratic discussion

- Perform a “thought experiment” where you borrow a friend’s car to drive, not knowing the this car’s speedometer reads faster than you are actually traveling. What speed will you actually be driving as you attempt to obey the speed limit?
- How do you suppose this miscalibration will affect the performance of the sour water stripping unit?
- Would this miscalibration be evident to an operator looking at the “faceplate” (graphic display) of FIC-28? Why or why not?
- For those who have studied calibration errors, would you characterize this error as a *zero shift*, a *span shift*, a *non-linearity*, or *hysteresis*?
- Explain why nearly every automatic control valve in this process is flanked by two “block” hand valves (one upstream and one downstream) and paralleled by a “bypass” hand valve.

file i02928

Question 7

In this process, nitric acid and ammonia vapor are combined to form a chemical called *ammonium nitrate*, a key ingredient in synthetic fertilizer. The “scrubber” vessel (V-5) uses a liquid spray to remove volatile chemical compounds from vapors before they exit out of an exhaust stack and into the atmosphere. As water evaporates from this liquid solution due to the heat of the vapors, a “make-up” system (loop #35) must add water to maintain a constant liquid level at the bottom of the scrubber vessel:



Suppose the last instrument technician to calibrate the positioner on the level control valve (LV-35) made a mistake, and the valve position is consistently open 10% more than it should be. For example, if controller LIC-35 sends a 50% (12 mA) control signal to the valve, the valve stem will settle at a position of 60% open instead.

Describe in detail the effect this mis-calibration will have on the performance of the level control system for the scrubber vessel.

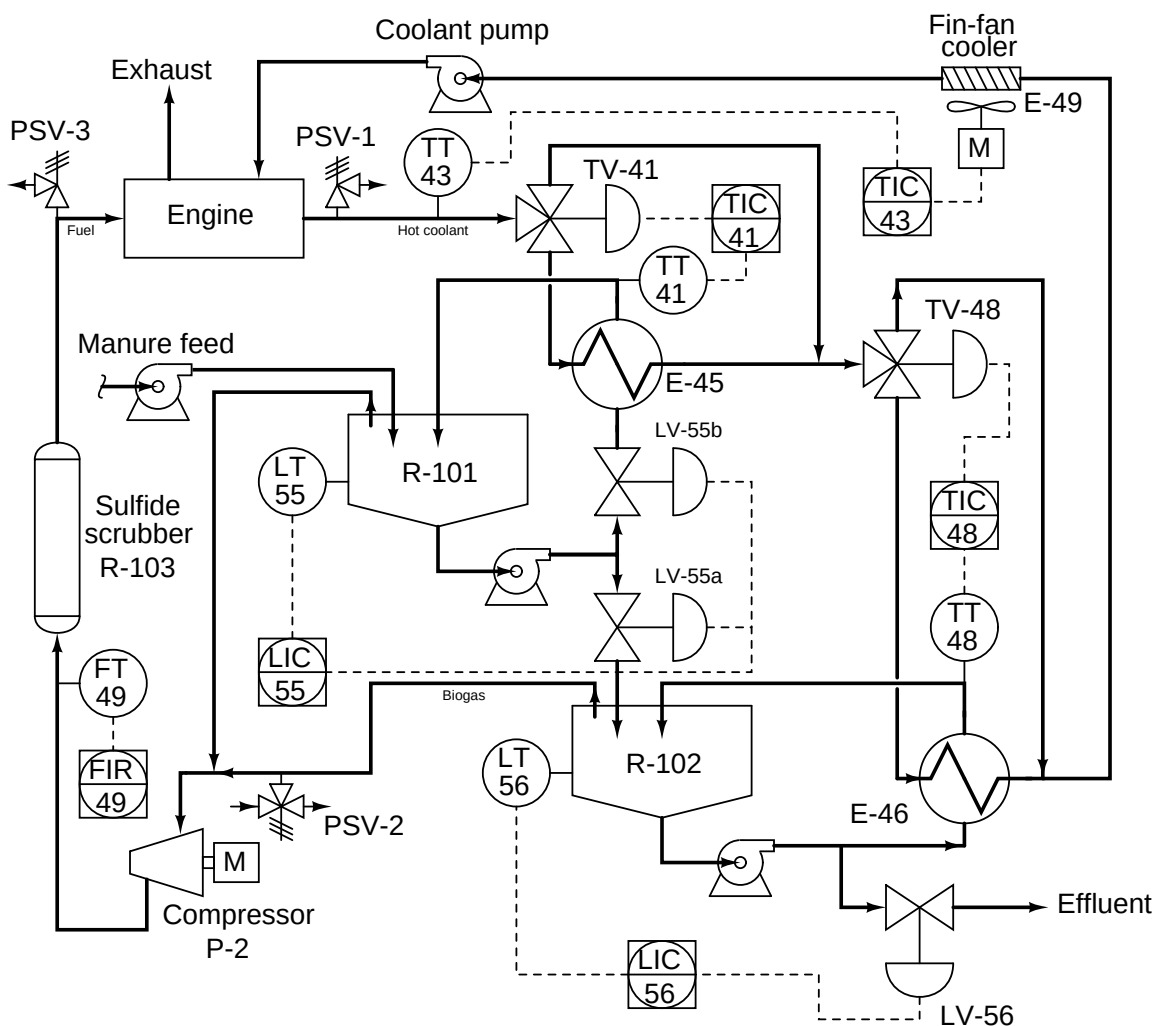
Suggestions for Socratic discussion

- Perform a “thought experiment” where you put on a pair of shoes with much thicker soles than you are accustomed to before driving a car. The extra thickness of your shoes’ soles results in the accelerator pedal being pressed down further than it would normally be for any given foot position. How will this affect your actual driving speed as you attempt to obey the speed limit?
- Is the scrubber vessel in danger of over- or under-filling from the valve’s mis-calibration?
- Which would be more dangerous or destructive in this process: an over-filled scrubber or an under-filled scrubber?
- What purpose does a “positioner” serve on a control valve?

[file i02929](#)

Question 8

In this biogas generation system, cow manure is used as a feedstock to produce methane gas (CH_4), which is then used to fuel an engine to turn a generator and make electricity. The waste heat from the engine is used to maintain the cascaded digesters (“reactors” R-101 and R-102) at optimal temperatures for anaerobic bacteria to digest the manure and produce biogas (approximately 105 °F):



Suppose digester R-102 is found to be at only 97 °F as indicated by a thermometer placed inside R-102 by an operator, even though temperature indicating controller TIC-48 shows the temperature at the outlet of the heat exchanger to be right at setpoint: 105 ° F. An instrument technician checks the calibration of TT-48 and finds it to be within $\pm 1\%$ of range (50 to 150 °F). Identify a probable cause for low temperature in R-102, and also how you would proceed to diagnose the process problem.

Suggestions for Socratic discussion

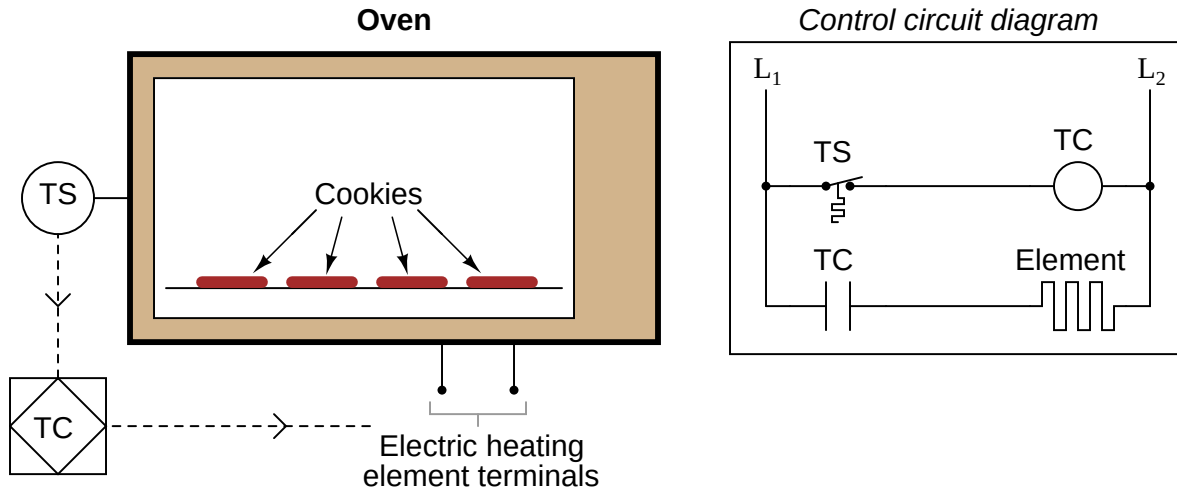
- Is there enough information provided in this P&ID to determine the proper direction of action for temperature controller TIC-48? Why or why not?
- Is there enough information provided in this P&ID to determine the proper direction of action for temperature controller TIC-43? Why or why not?

- Suppose an engineer suggested the reactor vessels be heated by electric heating elements, powered by an electric generator turned by the engine. Do you think this is a better or worse idea than using heat from the engine's coolant loop? Explain why or why not.
- For those who have studied control valve sequencing, identify the proper form of split-ranging for control valves LV-55a and LV-55b.

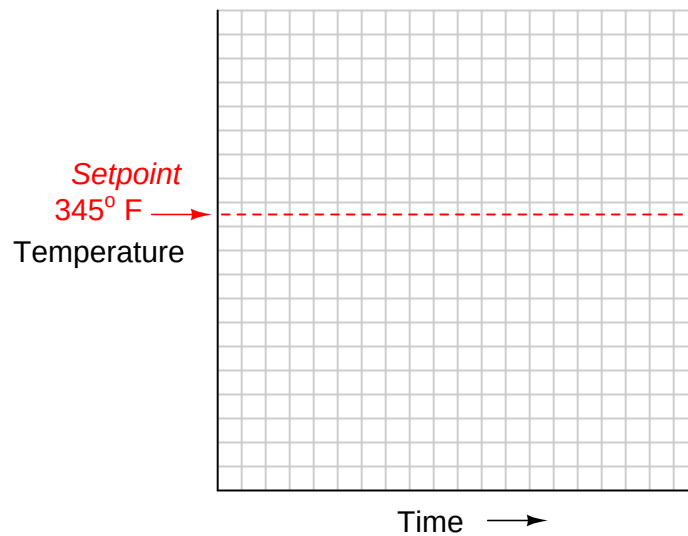
[file i01432](#)

Question 9

Suppose an electric oven is equipped with a temperature-sensitive control switch, which is wired to a control relay to send electric power to its heating element:



How would this simple *on-off* control system respond to changes in oven temperature, in its effort to maintain temperature at the setpoint? Be detailed in your explanation of the temperature switch and relay circuit's behavior. Also sketch a graph of the oven temperature over time:

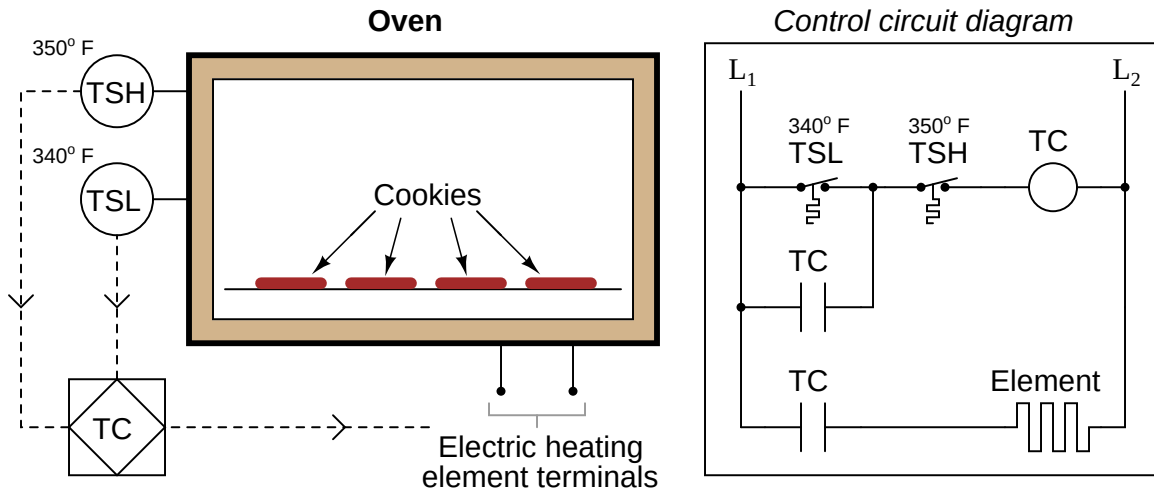


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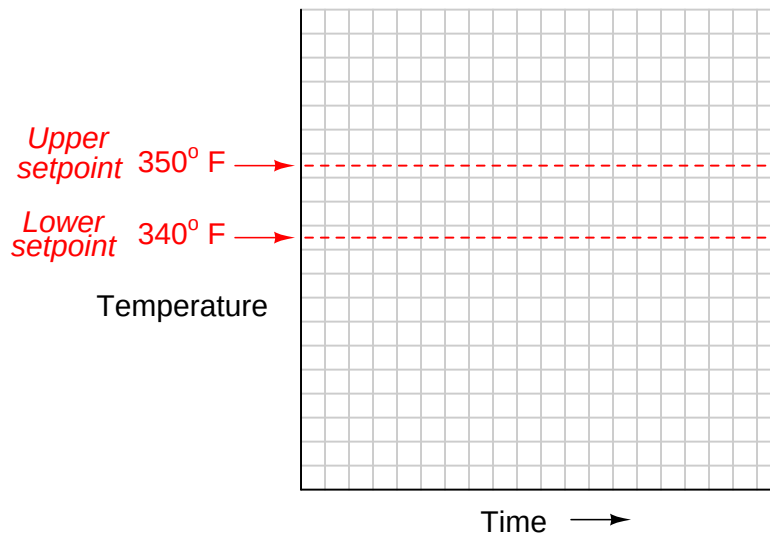
Question 10

One of the problems with simple on-off control is that the final control element “cycles” frequently. In real life, this may be a problem because frequent cycling means more wear and a shortened lifespan for the component.

An answer to this problem of frequent cycling is to design the system to have a “gap” or a “band” of control rather than a single setpoint. In effect, there are two setpoints: an upper and a lower setpoint. This is commonly referred to as *differential gap control*, or alternatively as *on-off control with deadband*. Shown here is a simple switch-and-relay circuit for a differential gap oven temperature control:



In the case of this electric oven, differential gap control means the heating element will not turn on until the temperature falls below the lower setpoint, and will not turn off until the temperature rises above the upper setpoint:

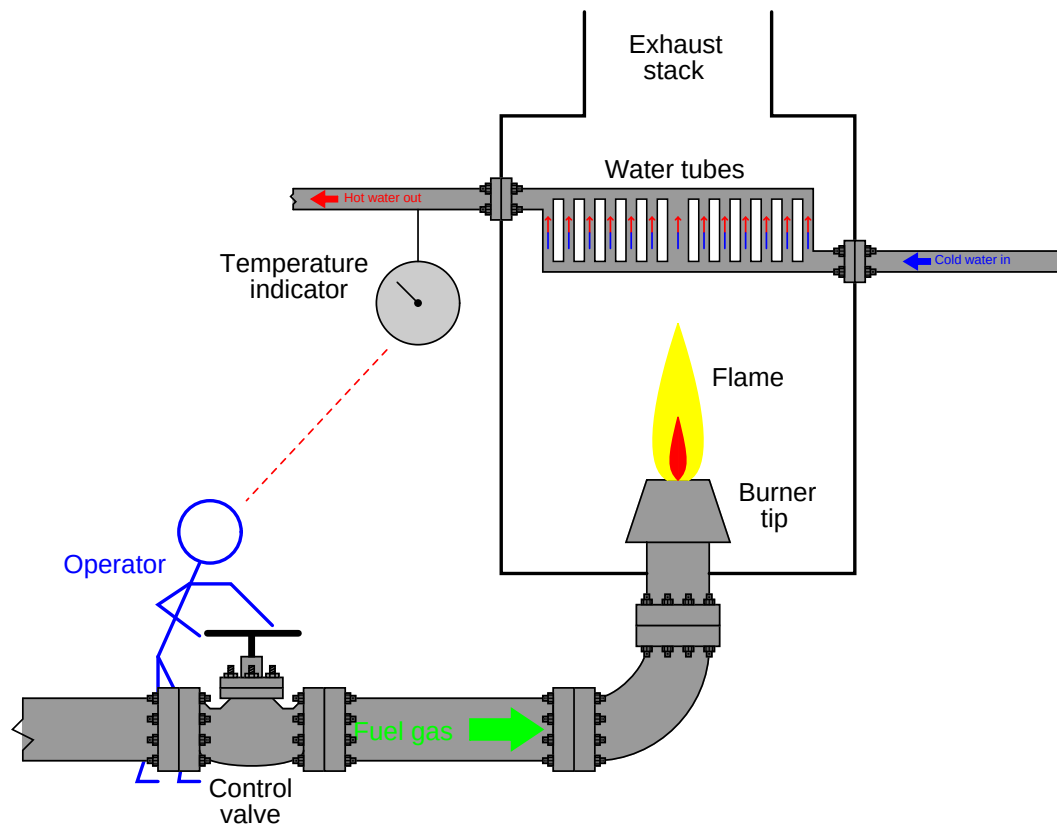


Graph this oven’s temperature over time as the control system operates, and contrast its behavior against that of a single-point on-off control system.

[file i01450](#)

Question 11

Suppose a gas-fired water heater is controlled manually, with a human operator observing a temperature indicator on the hot water outlet pipe and actuating a fuel gas control valve:



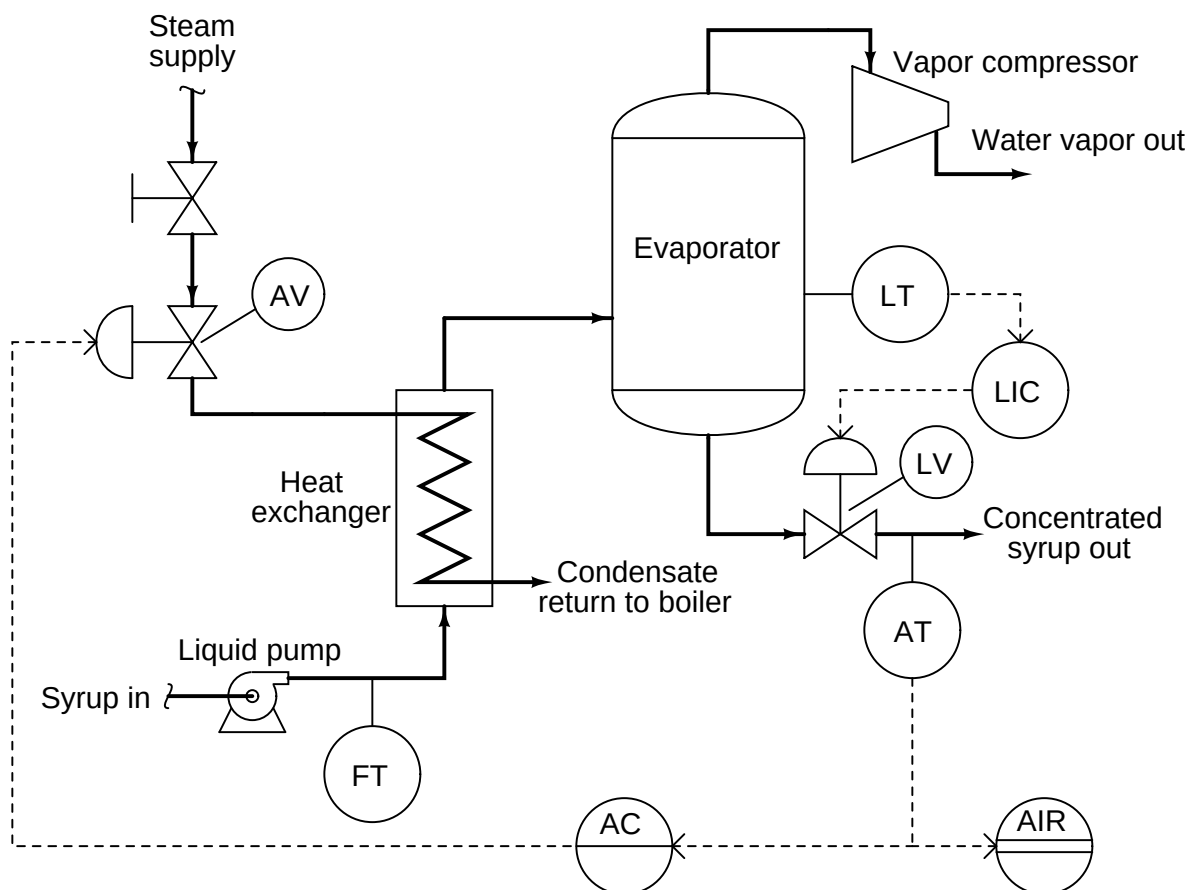
Does the operator play the part of a *direct-acting* controller, or a *reverse-acting* controller, in this process control scenario?

Also, identify the *process variable*, *setpoint*, and *manipulated variable* in this manual control system.

file i01452

Question 12

In this process, maple syrup is heated as it passes through a steam heat exchanger, then enters an evaporator where the water boils off. The purpose of this is to raise the sugar concentration of the syrup, making it suitable for use as a food topping. A level control system (LT, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Suppose the syrup analyzer (AT) suffers a sudden calibration problem, causing it to register too low (telling the analytical controller that the sugar concentration of the syrup is less than it actually is).

Describe in detail the effect this calibration error will have on the performance of the analytical control system.

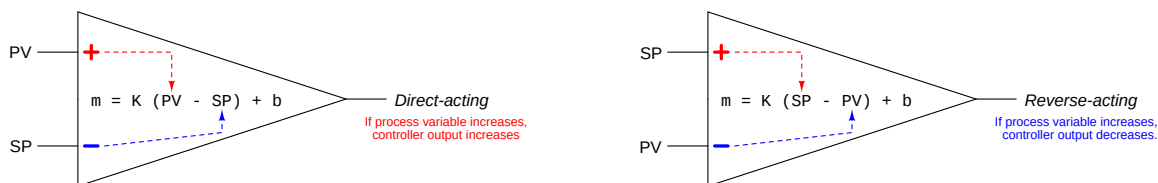
Suggestions for Socratic discussion

- What economic effect will this mis-calibration have on the process? In other words, does the process become more or less profitable as a result of this change?
- Suppose someone shuts the manual block valve on the steam line just a little bit, so that it is about 80% open instead of 100% open. How will this process change affect the control systems in this process?

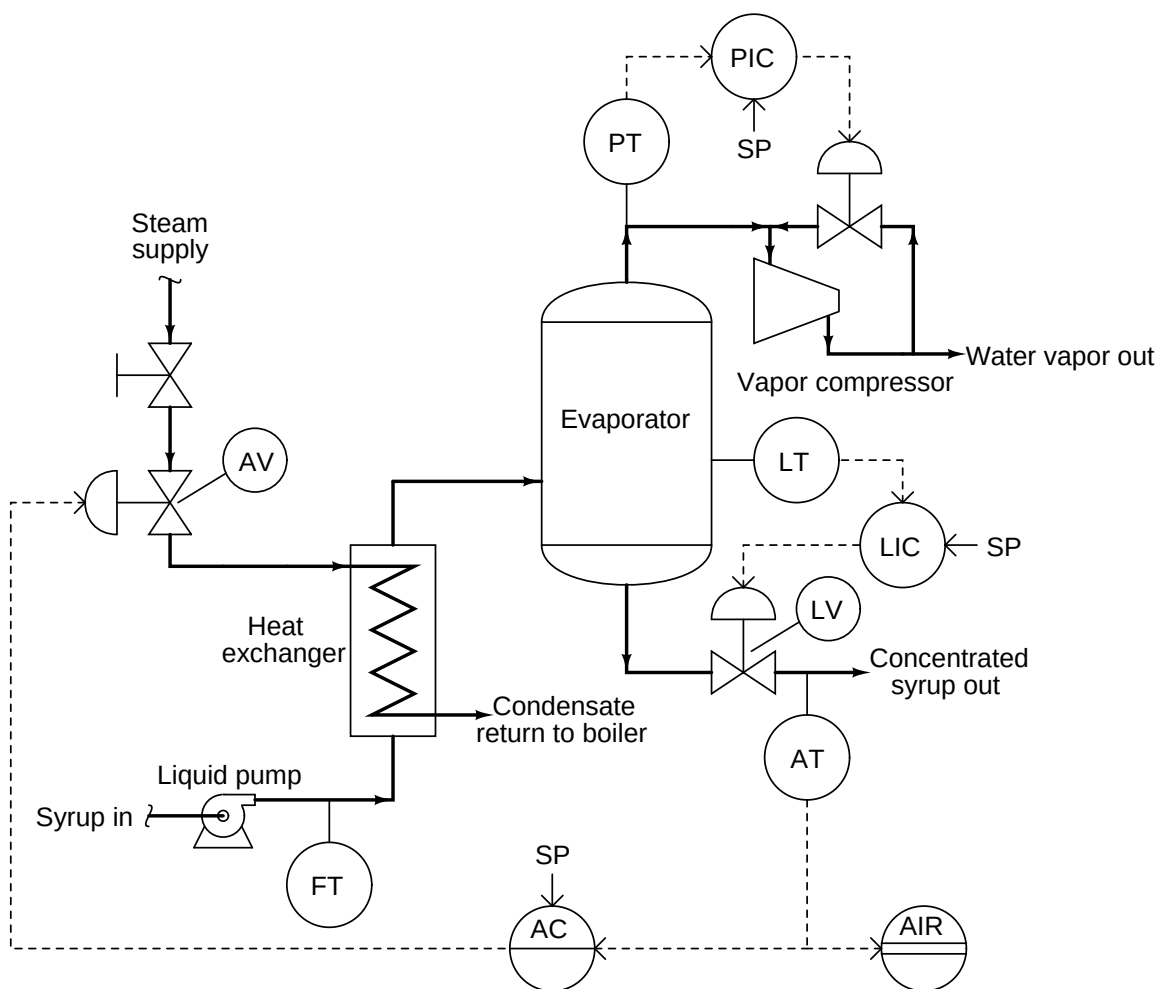
[file i02936](#)

Question 13

A helpful strategy for qualitatively analyzing control systems is to mark the inputs of all loop controller bubbles with either “+” or “−” labels to denote the direction of each controller’s action. This is the same symbology used to mark the inputs of an operational amplifier, where “+” represents the noninverting input and “−” represents the inverting input. The following illustration shows how the “+” and “−” inputs of an opamp relate to the characteristic equations for direct- and reverse-acting proportional controllers:

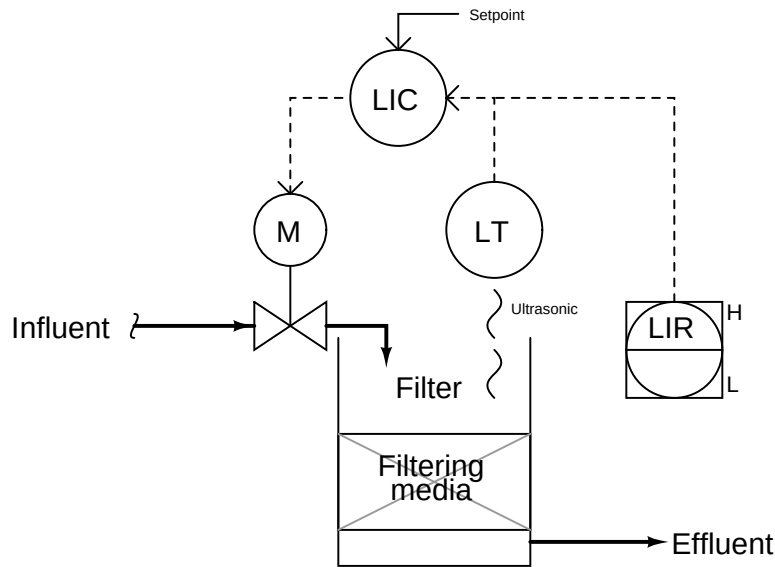


One way to get yourself into this mind-set of marking loop controller inputs with “+” and “−” symbols is to completely replace the ISA-standard “bubble” symbols with triangular opamp symbols. Try doing this in the following PFD, showing the proper direction of action for each controller for the maple syrup evaporator process by the proper orientation of the opamp symbols’ inverting and noninverting inputs (PV versus SP):



Question 14

This water filter level control system uses an ultrasonic level transmitter to sense the level of water in the filter, and a controller to drive a motor-actuated valve introducing raw water to be filtered:



Assuming a direct-acting level transmitter (increasing filter level = increasing signal), and a signal-to-open control valve (increasing controller output signal = wider open valve), determine whether the level controller needs to be configured for *direct-action* or *reverse-action*, and explain your reasoning. Annotate the diagram with “+” and “−” symbols next to the PV and SP controller inputs to show more explicitly the relationships between the controller inputs and output.

Next, determine the response of the controller to the following situations. In other words, determine what the controller’s output signal will do when this water level control system is affected in the following ways:

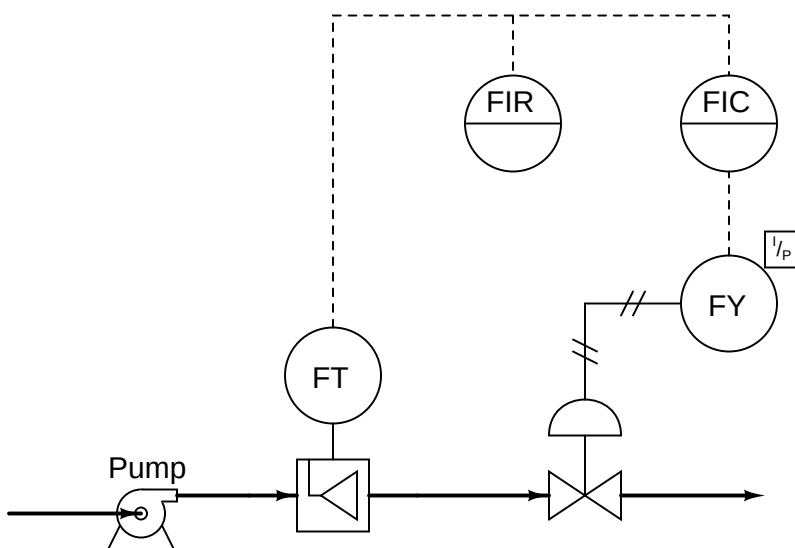
- A sudden increase in effluent flow rate (clean water demand)
- Level transmitter fails high (indicating 100% full water level)
- Control valve actuator fails, driving valve fully open (ignoring controller signal)

Suggestions for Socratic discussion

- Re-draw the diagram for this water filter level control system, replacing the controller (circle) with an op-amp symbol (triangle), determining the “+” and “−” input assignments on the opamp for PV and SP.
- Explain why level control is important in a water filter such as this.
- What do the “H” and “L” symbols near the LIR represent?

Question 15

There is a problem somewhere in this liquid flow control system. The controller is in automatic mode, with a setpoint of 65%, yet the flow indicator and the flow controller both register 0.3%: (nearly) zero flow. A P&ID of the loop appears here:



Explain how you would begin troubleshooting this system, and what possible faults could account for the controller not being able to maintain liquid flow at setpoint.

Suggestions for Socratic discussion

- Explain how you could divide this control system into distinct areas or zones which you may then begin to refer to when “dividing and conquering” the problem.

[file i02518](#)

Question 16

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the “Integral (Reset) Control” section of the “Closed-Loop Control” chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

[file i04284](#)

Question 22

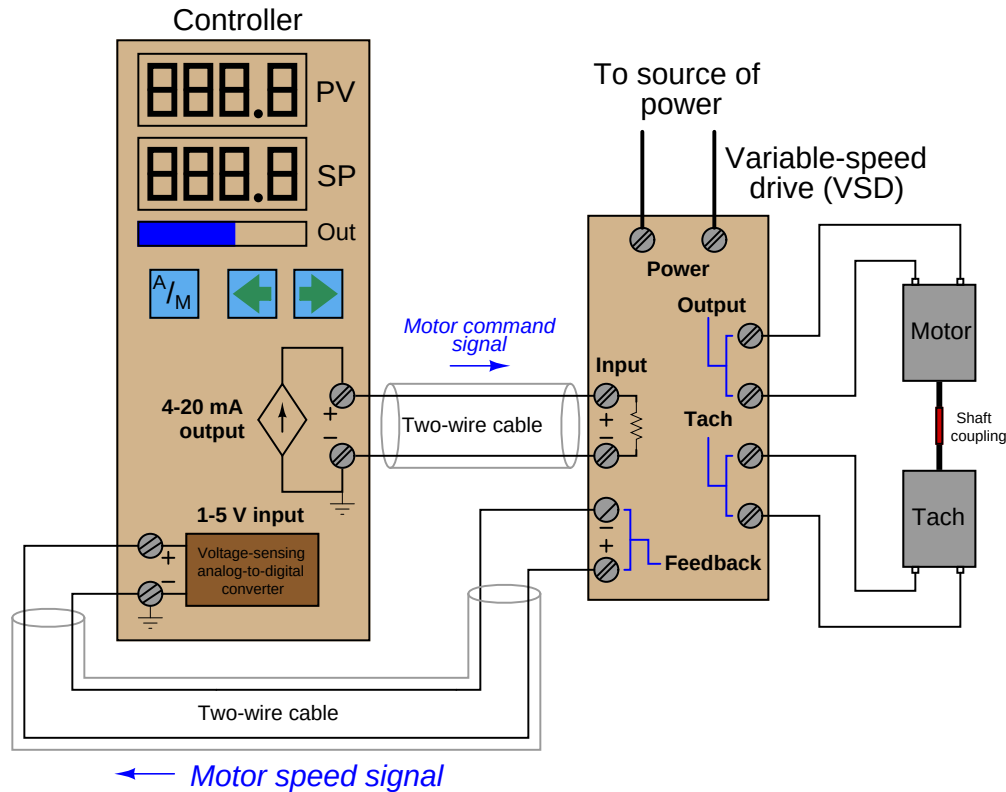
Read and outline the “Derivative (Rate) Control” section of the “Closed-Loop Control” chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

file i04301

Desktop Process exercise

PID (Proportional-Integral-Derivative) closed-loop control is a perplexing subject to master, without a doubt. An essential component of any course of study in PID control is adequate experimental time spent operating and tuning real PID-controlled processes. In this course, one of the ways you will gain hands-on experience with PID control is to operate a miniature process that easily fits on a desktop.

A simple diagram of this “Desktop Process” is shown here, where a single-loop controller controls the speed of a DC electric motor:



The motor receives its power from the Variable-Speed Drive (VSD), and reports shaft speed to the controller by means of a tachogenerator (“tach”) which generates a DC voltage proportional to shaft speed.

Determine the necessary action of the loop controller (*direct* or *reverse*), assuming that a greater current signal sent to the motor drive causes the motor to spin faster.

Suggestions for Socratic discussion

- If you do not have access to a Desktop Process, you may gain valuable experience tuning PID loops by using computer simulation software. Try searching the internet for free PID simulation programs, or web-based simulations you can run using a web browser. A popular (and free!) PID simulator program is made by *Dex Automation*.

[file i04257](#)

Desktop Process exercise

Configure the controller as follows (for “proportional-only” control):

- Control action = *reverse*
- Gain = 1 (Proportional Band = 100%)
- Reset (Integral) = *minimum effect = 100+ minutes/repeat = 0 repeats/minute*
- Rate (Derivative) = *minimum effect = 0 minutes*

Check to see that the controller is able to function in automatic mode (adjusting motor speed as you adjust the setpoint value). Now, you are set to experiment with the effect of different “gain” values in the PID algorithm. You may access the “gain” parameter by entering the controller’s *tuning* function.

Try setting the “gain” value to a number significantly less than 1, then changing the setpoint (SP) value several times to observe the system’s response. If you have a data acquisition (DAQ) unit connected to measure controller PV and output signal values, note the relationship between the two graphs plotted on the computer display following each setpoint change.

Now try setting the “gain” value to a number significantly greater than 1, changing the setpoint value again and again to observe the system’s response.

Answer the following questions:

- Which gain settings result in the swiftest response from the motor?
- Which gain settings result in the most sluggish response from the motor?
- Are there any gain setting values that result in *oscillation* of motor speed?
- Do you notice any *proportional-only offset*?
- Determine the “optimal” gain setting for your process resulting in swift response and minimum offset without too much oscillation.

Suggestions for Socratic discussion

- Generalizing to all proportional controllers, explain the effect of decreasing the controller gain value further and further.
- Generalizing to all proportional controllers, explain the effect of increasing the controller gain value further and further.

[file i04263](#)

Question 25

Desktop Process exercise

Configure the controller as follows:

- Control action = *reverse*
- Gain = *one-tenth the value yielding optimal control = ten times the proportional band value yielding optimal control*
- Reset (Integral) = *1 minute/repeat = 1 repeat/minute*
- Rate (Derivative) = *minimum effect = 0 minutes*

Use the controller's manual mode to establish the process variable at approximately 50%, then switch to automatic mode. Make a sudden setpoint adjustment (at least 10%, in either direction) and observe the controller's *slow* integral-action response to this change.

Try increasing the "aggressiveness" of the integral action (i.e. more repeats per minute, or fewer minutes per repeat) until a more satisfactory control response is seen from the controller. Without adjusting the controller's gain (proportional action), experiment with different integral settings until good control response is seen with large setpoint changes. Your goal is to achieve a quality of control that eliminates offset quickly while minimizing "overshoot" and oscillation of the process variable.

Suggestions for Socratic discussion

- Explain in your own words why more "repeats per minute" yields a more aggressive integral response, and why more "minutes per repeat" yields a tamer integral response.

file i04290

Question 26

Desktop Process exercise

Tune the controller in your Desktop Process first using proportional action only (reset and rate settings at minimum effect), testing the control quality by observing the graph produced by the data acquisition software. Your goal is quick response to setpoint changes with minimal oscillation of the PV.

After determining a reasonable value for the controller's gain setting, incorporate some reset (integral) action in order to eliminate offset following a setpoint or load change. Once again, your goal is quick response with minimal oscillation and overshoot of the PV.

Record these gain and reset settings for future use.

file i04292

Desktop Process exercise

Configure your Desktop Process for full proportional-plus-integral-plus-derivative (PID) control. Experiment with different “gain,” “reset,” and “rate” tuning parameter values until reasonably good control is obtained from the process (i.e. fast response to setpoint changes with minimal “overshoot,” good recovery from load changes). Record the “optimum” P, I, and D settings you find for your process, for future reference.

Compare the optimum PID tuning parameter values you arrived at compared to those of your classmates.

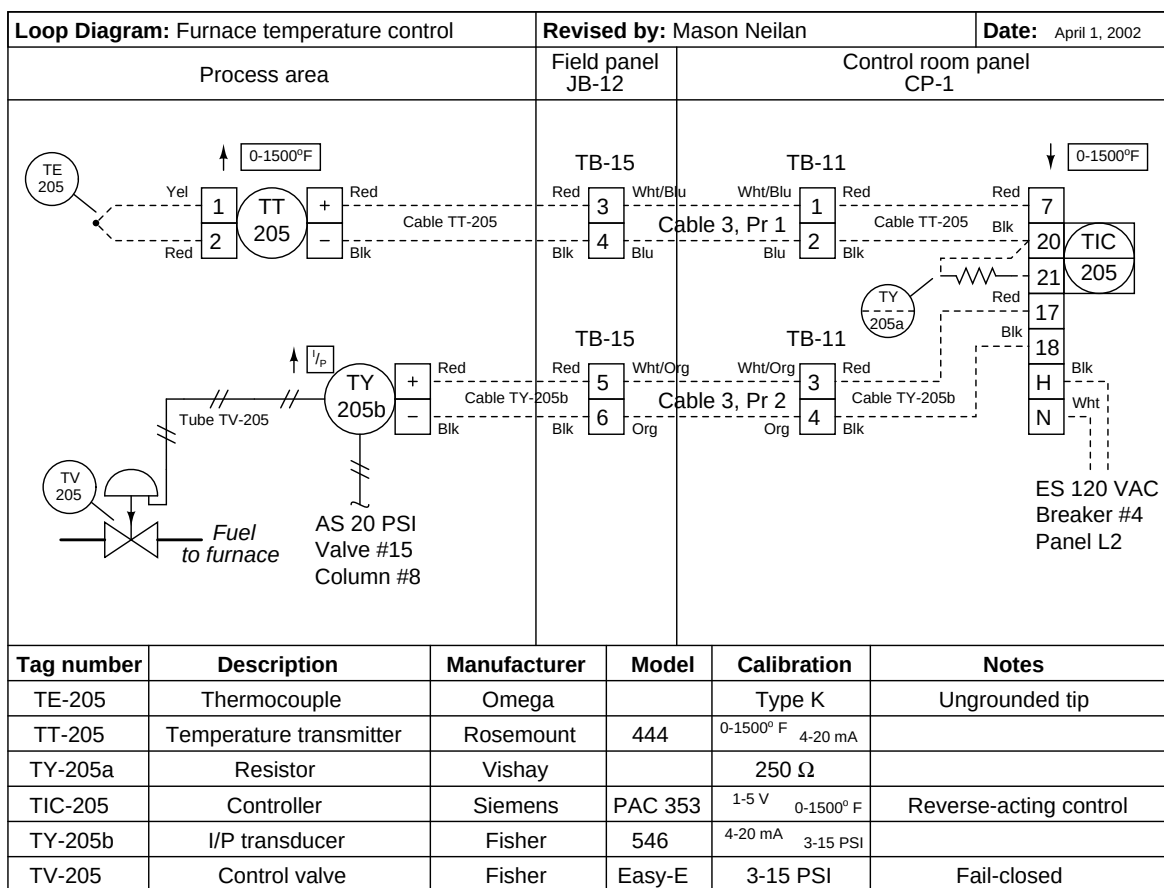
Suggestions for Socratic discussion

- How do the P, I, and D settings (when all used together to achieve optimum control) compare to the P setting by itself found to yield optimum proportional-only control, or the P and I settings found to yield optimum PI control, or the P and D settings found to yield optimum PD control?

[file i04309](#)

Question 28

This temperature control system has a problem. The process temperature is running above setpoint significantly – the setpoint is 850 °F and the temperature (as indicated by TIC-205) is 934 °F and showing no signs of cooling off over time:



The operator tells you the process was working just fine yesterday, holding right at the setpoint value of 850 °F. Your first step is to examine the faceplate of the controller: it is in automatic mode, and the output is at a value of -5% .

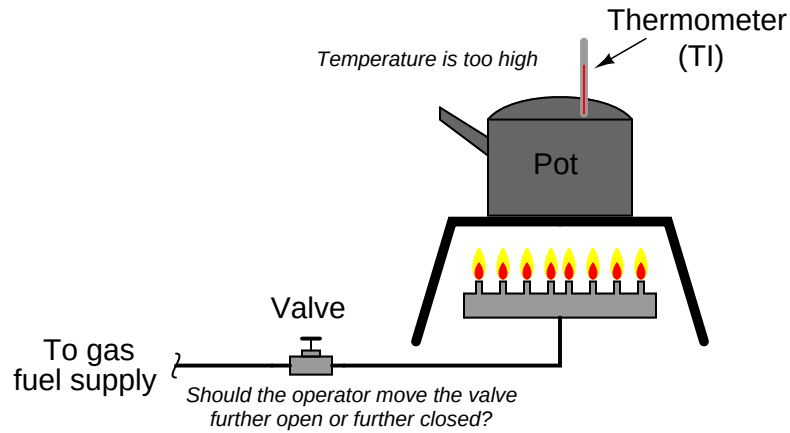
Explain the rationale behind checking the controller's mode and output value. How is this information helpful in troubleshooting the problem? What would be your next step in troubleshooting this problem? What might you do differently if you had seen the controller in a different mode, or with its output at some different (greater) value?

Suggestions for Socratic discussion

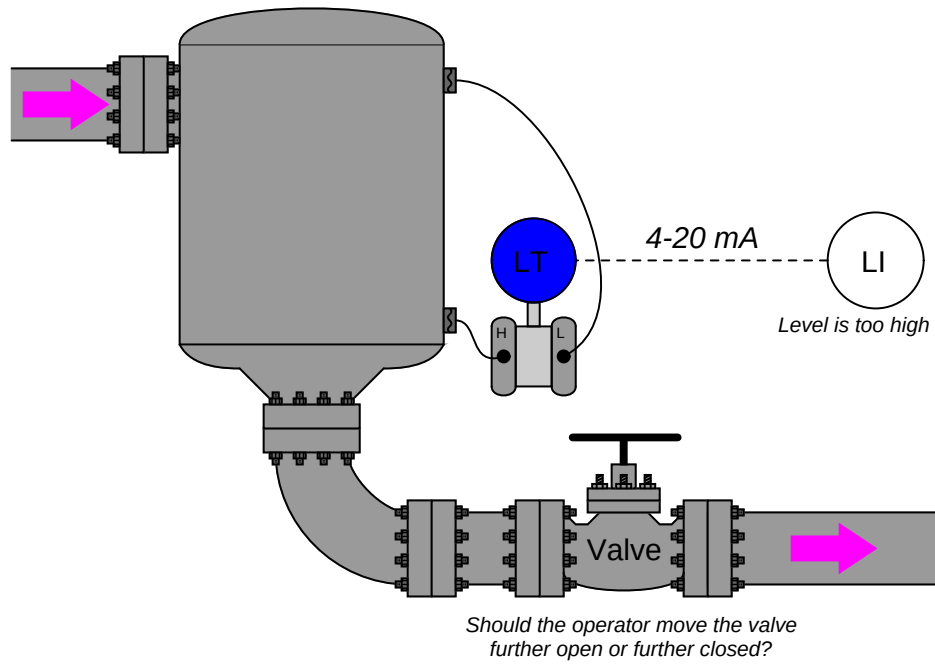
- How significant is the information that this process was working fine just yesterday? Would it make any difference to your diagnosis if you had been told this process has never worked right?
- Suppose this system were functioning perfectly well, and then something pinched Cable 3 Pair 2 and caused it to fail shorted. Explain what would happen as a result of this fault.
- Suppose this system were functioning perfectly well, and then something pinched Cable 3 Pair 1 and caused it to fail shorted. Explain what would happen as a result of this fault.

Question 29

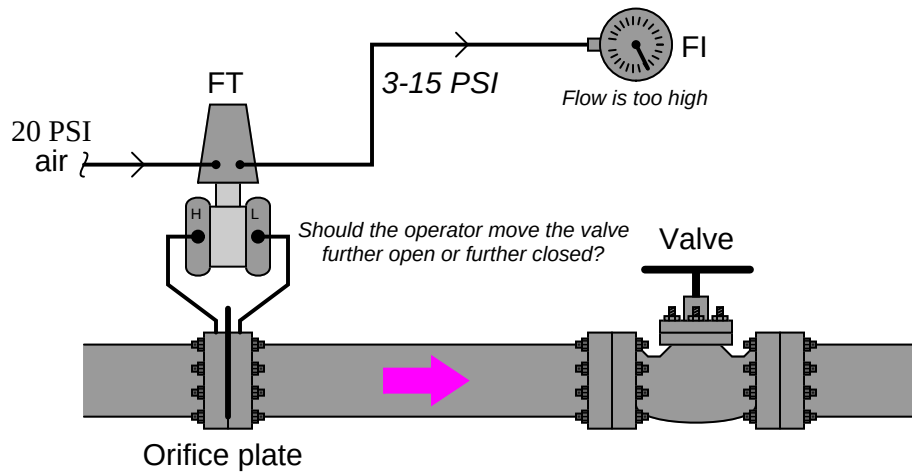
Suppose you were giving instructions to a human operator regarding which way to move a hand-operated control valve to maintain a process variable at setpoint. In each of these examples, determine which way the operator should move the valve to *counteract* an increase in the process variable resulting from some independent change in the process:

Example 1: Temperature control application

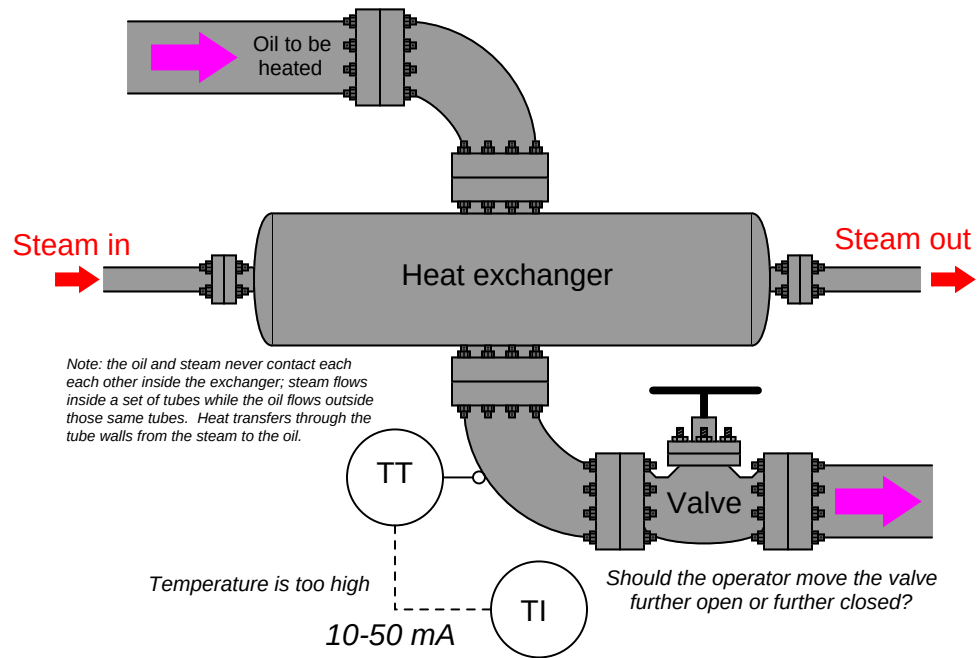
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



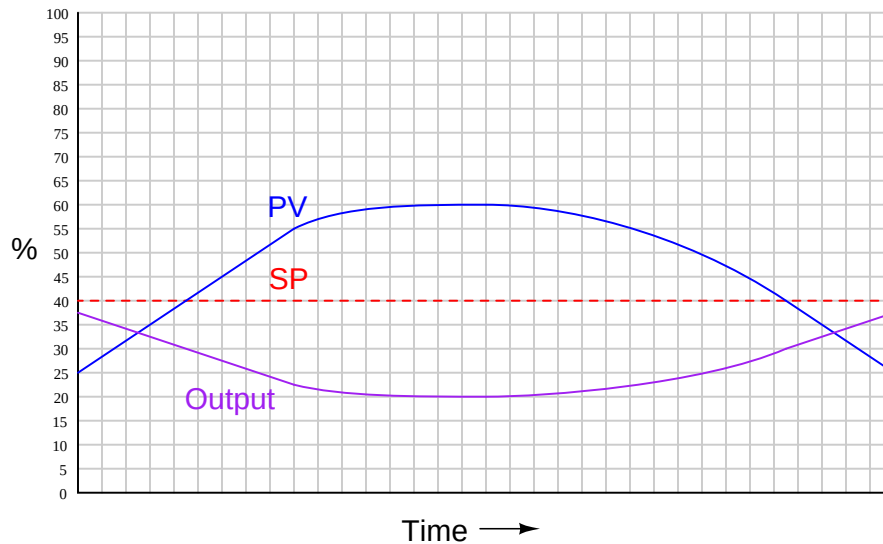
Suggestions for Socratic discussion

- Follow-up question: in which of these examples is the operator functioning as a *direct-action controller* and in which of these examples is the operator functioning as a *reverse-action controller*?

file i00109

Question 30

An indispensable tool for process operators and instrument technicians alike is the *trend* graph, showing such control loop variables as PV, SP, and controller Output superimposed on the same time-domain plot. The following example shows the process variable, setpoint, and output for a proportional-only controller as it responds to changes in a control loop's PV while the setpoint remains at a constant value of 40%:



Based on an examination of this trend graph, determine the *bias* value of the controller and *gain* value of the controller, as well as its direction of action (*direct* or *reverse*).

A helpful analysis technique when relating trend graphs to controller equations is to sketch a vertical line on the graph to identify some particular point in time, then identify the values of PV, SP, and Output at that point in time. A proper equation for the controller will successfully predict the Output value from the PV and SP values at *any* point in time shown on the trend.

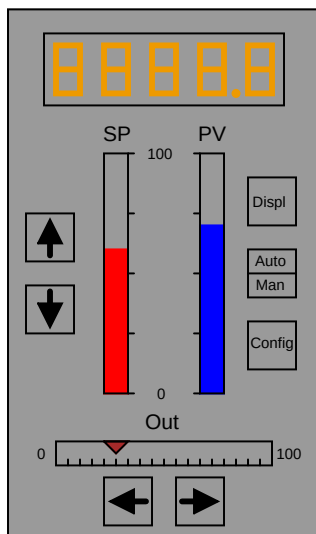
Suggestions for Socratic discussion

- Once you have calculated the gain of this loop controller, calculate its *proportional band* value as well.
- Build a computer spreadsheet program to model the behavior of the proportional controller in this scenario. You will know you are successful when it is able to duplicate any Output value shown on the trend graph at any particular point in time, corresponding to the PV and SP values at that same point in time.
- What would this trend look like if the controller were left in *manual* mode instead of *automatic* mode?

[file i00715](#)

Question 31

Shown here is the faceplate of a digital electronic single-loop process controller:



State your best guesses as to the functions of all buttons on this controller. In particular, elaborate on the difference between *Auto* and *Manual* modes, and which parameters the “arrow” buttons affect.

Also, describe what steps an operator would have to take to switch this controller from automatic to manual modes, and manually change the output signal going to the control valve, and describe a practical situation where the operator might be inclined to do such a thing.

[file i02373](#)

Question 32

In order to explore different process characteristics, it is useful to have access to loop simulation software you can run on your own personal computer. A “loop simulation” program mimics the behavior of a real process, allowing you to make tuning changes to a PID controller and see the results in a trend graph.

Some programs exist (for free download or streaming simulation) on the Internet allowing you to do this from your own personal computer. Research some of the available software options and try downloading at least one of them.

Be sure to bring your portable computer to class with you – ideally with the software already installed – for today’s classroom activities!

[file i04320](#)

Question 33

Desktop Process exercise

An important feature in any process controller is something called *output tracking*. This feature eases the transition from “Auto” mode to “Manual” mode. Using a Desktop Process, demonstrate this feature in action.

Another important feature in any process controller is something called *setpoint tracking*. This feature eases the transition from “Manual” mode to “Auto” mode. Using a Desktop Process, demonstrate this feature in action.

[file i01490](#)

Question 34

Question 35

Question 36

Question 37

Question 38

Question 39

Question 40

Read Section 10.0 of the Siemens model 353 Process Automation Controller user's manual (document UM353-1, Revision 11, March 2003). This section, entitled "Controller and System Test", describes how to test a model 353 controller by stepping through a set of exercises designed to explore its major features. It also doubles as an excellent exercise for students to use in understanding this controller's features and capabilities.

To do this exercise, you will need access to a Siemens model 353 controller. Feel free to use one of the panel-mounted 353 controllers in the lab, or one of the Desktop Process units, or even a 353 controller taken from storage. It is definitely a hands-on activity!

10.1.1 Connections and Power

This subsection describes how to connect AC power to the controller, and also how to connect the output to the PV input for the purposes of the subsequent tests. Feel free to skip this second part, especially if your controller is already connected to a real process. Proceed through each of the subsections, following the step-by-step instructions.

10.1.2 Configuration

This subsection refers you to another section of the manual, instructing you to load Factory Configured Option number 101 (FCO 101).

10.1.3 Input/Output

This subsection shows you how to verify the Setpoint, Output, and Process Variable I/O as configured in FCO 101, and points you to the diagram of FCO 101 to verify the "connections" of P, S, and V in the ODC function block.

10.1.4 Auto/Manual

This subsection shows you how to test the Automatic and Manual modes.

10.1.5 Modifying an FCO

This subsection shows you how to make changes to the function blocks within FCO 101. The changes include:

- Adding a new function block to FCO 101
- Perusing parameters inside a function block
- Changing MINSIZE and MAXSIZE parameters of the AIN1 function block

10.1.6 Alarms

This subsection shows you how to change the alarm values and priorities. The instructions imply a connection between output and PV input, such that you can simulate any PV signal desired simply by switching to manual mode and adjusting the output. If your controller is connected to a working process, I recommend running the controller in automatic mode and adjusting the setpoint to make the PV go to the desired value(s).

10.1.7 Tag

This subsection shows you how to change the “tag” name of the loop.

10.1.8 Quick

This subsection explores the “Quick” set feature to change certain parameters in any function block. In this particular case, the instructions guide you to configuring a ramping setpoint value.

10.1.9 Tune

This subsection explores the “Tune” feature to change P, I, and D tuning parameters, and also to activate autotune. If your controller is connected to a working process, feel free to engage the “autotune” feature and see how well it does. In my general experience a competent technician can always achieve more robust control through careful hand-selection of tuning parameter than by relying on an autotune feature, but go ahead and try it just for fun.

10.1.10 View

This subsection explores the “View” feature to monitor variables inside the controller. This can be a very useful diagnostic tool, especially when developing and “debugging” new function-block programs.

Suggestions for Socratic discussion
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- Suppose you wished to change the “connection” path between two function blocks in a program. Demonstrate how to do this.
- Suppose you wished to take the factory configured option program #101 and add a discrete output block, then connect that block to the alarm block so that an external alarm light could be controlled by the alarm settings in the controller. Demonstrate how to do this.
- Identify some of the different Factory Configured Options (FCOs) available to you.
- In section 10.1.5 a clever way is shown to change the upper range value of the AIN function block from 100 to 500. Instead of simply turning the pulser knob to increment 100 to 500, some decimal-point shifting is used. Explain how this works.
- Section 3.2.12 describes the meaning of five different priority levels for alarms in the ALARM function block. Explain these priority levels in your own words.
- In section 10.1.8 describes one of the quick-set parameters as “POWER UP SETPOINT”. Explain what this parameter is useful for, citing a practical application if possible.

file i00808

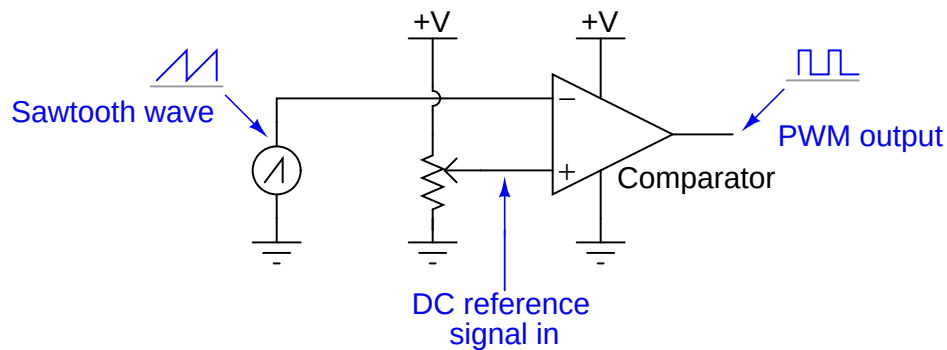
Question 42

Examine the “Siemens/Moore 353 program for pulse-width modulation” contained on your Instrumentation Reference, showing a function block program for equipping the 353 controller with a PWM output signal (modulated on/off) rather than an analog 4-20 mA output signal, then answer the following questions:

Identify those function blocks which are connected identically to the standard Factory Configured Option 101 program, then identify those function blocks which are different.

Explain why anyone would wish to have a loop controller equipped with a PWM output instead of a 4-20 mA analog output.

Explain how this analog circuit functions to produce a PWM output signal from a sawtooth waveform and a DC reference signal, and how this functionality is mimicked by the function block program of the Siemens 353 controller:



Suggestions for Socratic discussion

- Describe the steps necessary to edit the FCO 101 program so that it resembles this program, using the faceplate pushbutton controls and displays.
- Which way would you have to move the wiper on the potentiometer in the analog circuit in order to increase the duty cycle of the PWM output?
- What would be the effect of the +V power source connection to the potentiometer failing open?
- What would be the effect of the ground connection to the potentiometer failing open?
- What would be the effect of the sawtooth wave generator connection failing with a 0 volt output?
- What would be the effect of the +V power source connection to the comparator failing open?
- Sketch the diagram of an “interposing” circuit that can take the opamp’s output signal and amplify it to drive PWM power to a large electric heating element (e.g. rated at a much greater voltage such as 240 VAC).

file i00356

Question 43

Read the Siemens model 353 controller application note on “Ethernet Peer-to-Peer Communication With Model 353 and Procidia i/pac Controllers” (document AD353-113, Revision 1, July 2002), then answer the following questions:

The communication protocol used by model 353 controllers is *Modbus TCP/IP*. Explain how this differs from implementations of Modbus you have seen in RS-485 networks.

Explain how the AIE and AOE function blocks are used in a pair of model 353 controllers to exchange analog signal data between the two. Does one controller *read* data from another controller, or does it *write* data to another controller, or can both events take place?

The “Ethernet Function Block” section does presents a good example of how the subnet mask is used to identify a range of IP addresses that controllers may communicate between. Read the example given and explain in your own words how the subnet mask works.

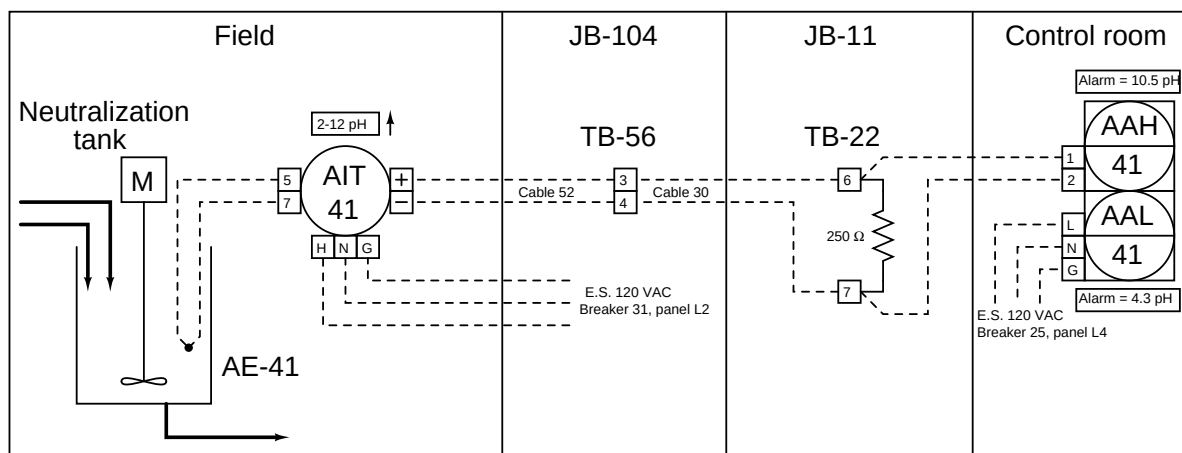
Suggestions for Socratic discussion

- Explain why communicating variables via Ethernet would be considered an advantage to a single-loop controller such as the Siemens model 353. Why not just communicate all process-related variables via 4-20 mA analog signals over twisted-pair instrument cables?
- Identify any disadvantages to communicating process data between controllers using Ethernet. Can you think of any faults that could really cause control problems in a system using Ethernet to exchange process data between controllers?
- If you had the choice of connecting multiple Ethernet-capable controllers together, would you opt for an Ethernet *switch* or an Ethernet *hub* as the connecting node between controllers? Explain your reasoning.
- Modbus is designed to employ master-slave arbitration. Ethernet is uses CSMA/CD arbitration. How is it possible for Modbus to work over an Ethernet connection if the two arbitration protocols are different?

file i00716

Question 44

This pH monitoring system triggers an alarm if the pH value of the process water in the neutralization tank drifts past either of two threshold (trip) values:



Answer the following questions about this pH alarm system:

- If a wire breaks loose at TB56-4, creating an “open” fault in the loop circuit, determine what will happen at the alarm unit (AAH, AAL-41) and also where you would expect to measure voltage in the loop circuit and where you would expect to measure *no* voltage in the loop circuit.
- If breaker #25 in panel L4 suddenly trips, what will happen in this system? Will an operator still be able to read the pH value of the water in the neutralization tank?
- If a fire breaks out near the conduit through which cable 52 runs, causing the plastic insulation around the conductors of cable 52 to melt and consequently causing those conductors to *short* together, what will happen in this system? Where would you expect to measure voltage in the loop circuit, and where would you expect to measure *no* voltage in the loop circuit? Where would you expect to measure current in the loop circuit, and where would you expect to measure *no* current in the loop circuit?
- Calculate the loop current value when the pH measures 6.8 inside the neutralization tank.

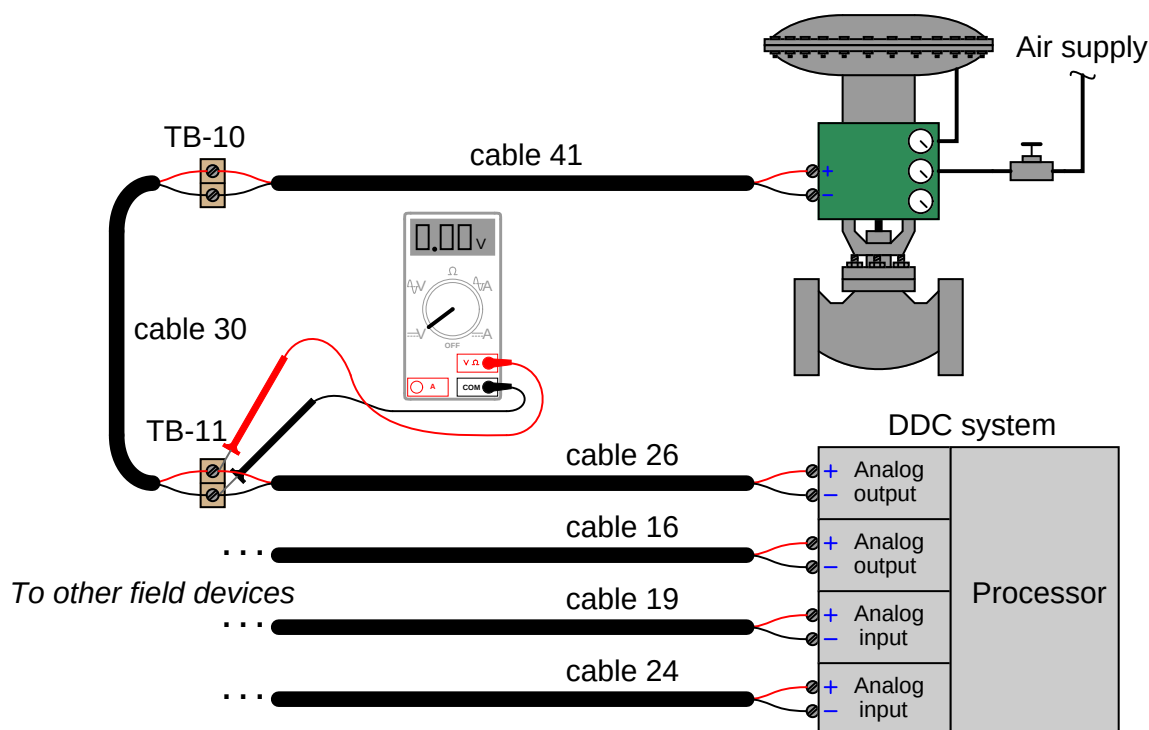
Suggestions for Socratic discussion

- For those who have studied pH measurement, explain why pH “neutralization” is an important control process in industry.
- How can we tell from this diagram whether the 4-20 mA output of transmitter AIT-41 is *active* or *passive* (i.e. *sourcing* or *sinking*)?

[file i00239](#)

Question 45

A DDC (Direct Digital Control) system used for building automation sends a 4-20 mA control signal to a steam valve with an electronic positioner. This particular loop has a problem, for the valve remains in the full-closed (0%) position regardless of what the DDC tries to tell it to do. A technician begins diagnosing the problem by taking a DC voltage measurement at terminal block TB-11 in this loop circuit:



The technician knows a reading of 0 volts could indicate either an “open” fault or a “shorted” fault in the wiring. Based on the location of the measured voltage (0.00 VDC), determine where in the wiring a single “open” fault would be located (if that is the culprit), and also where in the wiring a “shorted” fault would be located (if that is the culprit).

For the next diagnostic test, the technician disconnects the red wire of cable 30 where it attaches to the screw terminal on TB-11, and re-measures voltage at TB-11. After disconnecting the wire, the new voltage measurement at TB-11 still reads 0.00 volts. Determine what this result tells us about the nature and location of the fault.

Suggestions for Socratic discussion

- Explain why it is critically important to determine the identities of the valve and DDC card as being either electrical *sources* or electrical *loads* when interpreting the diagnostic voltage measurements.
- Identify some of the pros and cons of this style of testing (measuring voltage at a set of points before and after a purposeful wiring break) compared to other forms of multimeter testing when looking for either an “open” or a “shorted” wiring fault.
- Identify a fault other than open or shorted cables which could account for all the symptoms and measurements we see in this troubleshooting scenario.

[file i00792](#)

Question 46

Question 47

Question 48

Question 49

Question 50

Question 51

Question 52

Question 53

Question 54

Question 55

Question 56

Question 57

Question 58

Question 59

Question 60

Question 61

Read and outline the “Distributed Control Systems (DCS)” subsection of the “Digital PID Controllers” section of the “Closed-Loop Control” chapter in your *Lessons In Industrial Instrumentation* textbook. Note the page numbers where important illustrations, photographs, equations, tables, and other relevant details are found. Prepare to thoughtfully discuss with your instructor and classmates the concepts and examples explored in this reading.

[file i00813](#)

Question 62

Search through Chapter 1 (“DeltaV System Overview”) of the “Getting Started with your DeltaV Digital Automation System” manual (document D800002X122, March 2006) to answer the following questions:

Based on the simple network diagram shown on page 1-1, what type of digital network connects the PC workstation(s) to the DCS controller?

What is the *System Identifier* in a DeltaV system, and what purpose does it serve?

Several software applications find frequent use in the maintenance and operation of a DeltaV control system: *DeltaV Explorer*, *DeltaV Operate Run*, *DeltaV Operate Configure*, *Control Studio*, and *DeltaV Books Online*. Identify what each of these software tools does.

Suggestions for Socratic discussion

- A hallmark of Distributed Control Systems (DCSs) is *hardware redundancy*. Identify specific redundant features of the Emerson DeltaV DCS.
- Access a DeltaV workstation PC and try opening each of the software applications listed, exploring the features of each. *Do not “download” or “save” anything, which will alter the configuration of the DCS – just explore and observe!*

file i00811

Question 63

Read Exercise 5 (“Creating a New Module (LI-101) from Scratch”) in Chapter 4 (“Creating and Downloading the Control Strategy”) of the “Getting Started with your DeltaV Digital Automation System” manual (document D800002X122, March 2006) and answer the following questions:

Which function block type is used in the LI-101 module, and what does it do?

The output of the main function block in this module is “wired” to another object called an *Output Connector*. What does an “output connector” do in the DeltaV system?

One of the configuration steps described has you add “History Collection” to the function block. What exactly does this feature do?

After this module’s function block has been “wired” to the Output Connector, there are a few final steps required to finish the module. Identify these steps and explain their purpose.

Suggestions for Socratic discussion

- Access a DeltaV workstation PC and try opening a module using Control Studio. Find some of the AI block parameters and options discussed in this exercise. *Do not “download” or “save” anything, which will alter the configuration of the DCS – just explore and observe!*
- Compare the setting of the process variable’s “engineering units” to the MINSCALE and MAXSCALE parameters of the AI function block in a Siemens 353 loop controller. How are these tasks similar, and how are they different?

file i00812

Question 64

Read Exercise 6 (“Creating a PID Control Loop (FIC-101) from Scratch”) in Chapter 4 (“Creating and Downloading the Control Strategy”) of the “Getting Started with your DeltaV Digital Automation System” manual (document D800002X122, March 2006) and answer the following questions:

In this exercise the user is shown how to begin configuring a control module without starting from scratch as in Exercise 5. How is this done?

Although you will often find PID function blocks “wired” to analog input (AI) function blocks and analog output (AO) function blocks to make a complete working loop module, here in this exercise the PID function block stands alone. In lieu of AI and AO function blocks to route the signals to and from real-world I/O channels, how does this PID function block “know” where to get its PV input and where to send its MV output signals?

Suggestions for Socratic discussion
--

- Access a DeltaV workstation PC and try opening a module using Control Studio. Find some of the PID block parameters and options discussed in this exercise. *Do not “download” or “save” anything, which will alter the configuration of the DCS – just explore and observe!*
- Note where the controller’s direction of action (i.e. “direct” or “reverse” action) is selected in the PID function block. How does one determine the correct direction of control action for any specific process?
- Immediately following the instruction on how to set controller’s direction of action (i.e. “direct” or “reverse” action), this exercise specifies how to set a similar parameter in the IO-OPTS collection of parameters called *Increase to Close*. This is used when the control valve happens to be air-to-close (fail-open), to make the controller faceplate’s output bargraph match the valve stem position (so that a displayed output of 0% represents a shut valve and a displayed output of 100% represents a wide-open valve). Explain why this parameter is an important one to set in processes where the control valve is air-to-close. One way of explaining the importance of this parameter is to describe what would happen if it were *not* set correctly for a particular control loop.
- Compare the setting of the process variable’s “engineering units” to the MINSIZE and MAXSIZE parameters of the AI function block in a Siemens 353 loop controller. How are these tasks similar, and how are they different?

[file i00814](#)

Question 65

Read Exercise 9 (“Downloading the Modules”) in Chapter 4 (“Creating and Downloading the Control Strategy”) of the “Getting Started with your DeltaV Digital Automation System” manual (document D800002X122, March 2006) and answer the following questions:

The final step in implementing control modules in the DeltaV system is to do a “download.” Explain what this procedure accomplishes, and what would happen if we forgot to do it.

An “Important” warning note is given on page 4-53 of this tutorial. Explain in your own words what you need to be cautious about.

[file i00816](#)

Question 66

Search through Chapter 5 (“Creating Operator Pictures”) of the “Getting Started with your DeltaV Digital Automation System” manual (document D800002X122, March 2006) to answer the following questions:

Identify a fast way to switch between the “Run” and “Configure” modes of *DeltaV Operate*.

This tutorial advises against creating a new “picture” file from scratch. Instead, what is the recommended method for creating a graphical screen for operators to use?

Describe the purpose of the *DeltaV_Toolbox* in *DeltaV Operate* (Configure mode), and how this “toolbox” may be used to create graphic objects on the screen for operator displays.

Explain what a “link” is in *DeltaV Operate*. Specifically, what is a “datalink” and what might one be used for?

Explain what a “parameter reference” is in *DeltaV Operate*.

Explain what a “dynamo” is in *DeltaV Operate*.

Page 5-30 begins a discussion on Trend Links, which is another form of link supported by *DeltaV_Run*. In this discussion the tutorial mentions that trend links are able to display any “floating point” data (i.e. any parameter reference ending in .F.). Explain what “floating point” data is and how it differs from integer or boolean data.

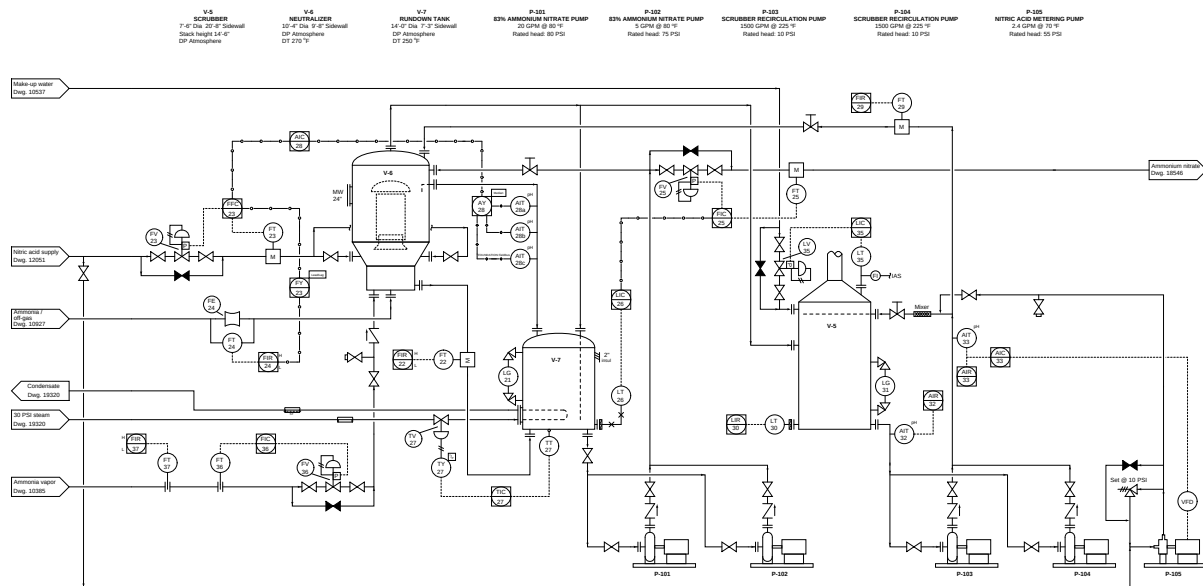
Suggestions for Socratic discussion

- Access a DeltaV workstation PC and try opening an operator picture using DeltaV Operate Configure. Explore the parameters associated with the datalinks and dynamos in this picture. *Do not “download” or “save” anything, which will alter the configuration of the DCS – just explore and observe!*
- For those students who have studied HMI programming in their PLC coursework, identify aspects of *DeltaV Operate* that are similar to other HMIs you have worked with.
- Identify practical applications where you might wish to show *integer* data on an operator display.
- Identify practical applications where you might wish to show *boolean* data on an operator display.

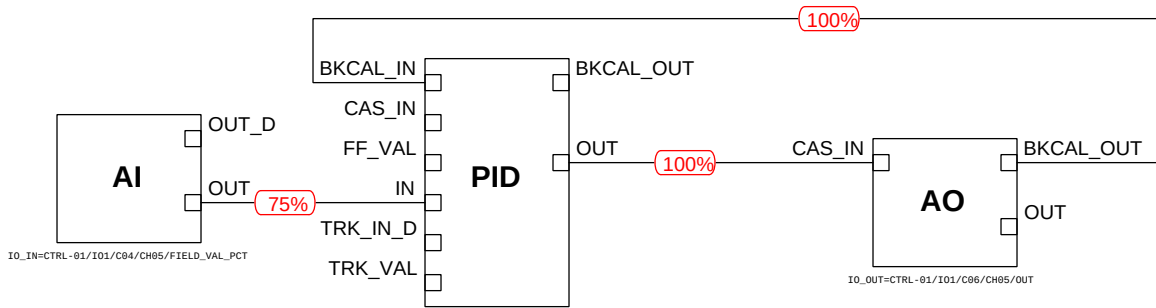
file i00817

Question 67

The scrubber (vessel V-5) liquid level is being controlled by an Emerson DeltaV DCS, but something is wrong. The operator reports seeing a liquid level of 90% in the LG-31 sightglass while claiming the setpoint entered into the DeltaV Operate controller faceplate is 75%:



A very useful feature of the *DeltaV Control Studio* application is being able to switch the view to “online” mode and watching real-time numerical data appear on the interconnecting lines between function blocks. When you use the *Control Studio* software to examine this loop’s function block program module in online mode, this is what you see:



Identify the likelihood of each specified fault in this process, based on what you see in the online Control Studio view. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this process.

Fault	Possible	Impossible
Poor tuning in the PID function block		
LT-35 miscalibrated, reading too low		
LT-35 miscalibrated, reading too high		
Make-up water source shut off		
Pump P-103 failed (not pumping)		
LG-31 sightglass block valve plugged		
Pump P-105 failed (not pumping)		
Human operator error		

[file i00961](#)

Question 68

Sketch a diagram showing all wire connections between any model of Rosemount differential pressure transmitter, an Emerson DeltaV DCS controller, and a Fisher DVC6020 valve positioner to form a simple PID control system. You may arbitrarily choose to use either “M-series” or “S-series” DeltaV I/O cards. Your task is to locate the appropriate datasheets or manuals in the Instrumentation Reference (or online) to identify the proper wire terminals to connect, then sketch a simple loop diagram showing how the appropriate terminals on each device connect to terminals on the other devices to make a functional instrument loop. You are free to choose which channel on the DeltaV I/O cards to use for your loop.

Suggestions for Socratic discussion

- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks (+, −) for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.
- Locate a wiring diagram for one of the *redundant* I/O card options available for the DeltaV system (either M-series or S-series) and reference that diagram to explain how redundant I/O cards connect to the same field instrument.

[file i00818](#)

Question 69

Read Exercise 8 (“Creating a Sequential Function Chart”) in Chapter 4 (“Creating and Downloading the Control Strategy”) of the “Getting Started with your DeltaV Digital Automation System” manual (document D800002X122, March 2006) and answer the following questions:

Describe what a SFC program does, explaining how an SFC could be used to help automate some real-life process.

[file i00815](#)

Question 70

Question 71

Question 72

Question 73

Question 74

Question 75

Question 76

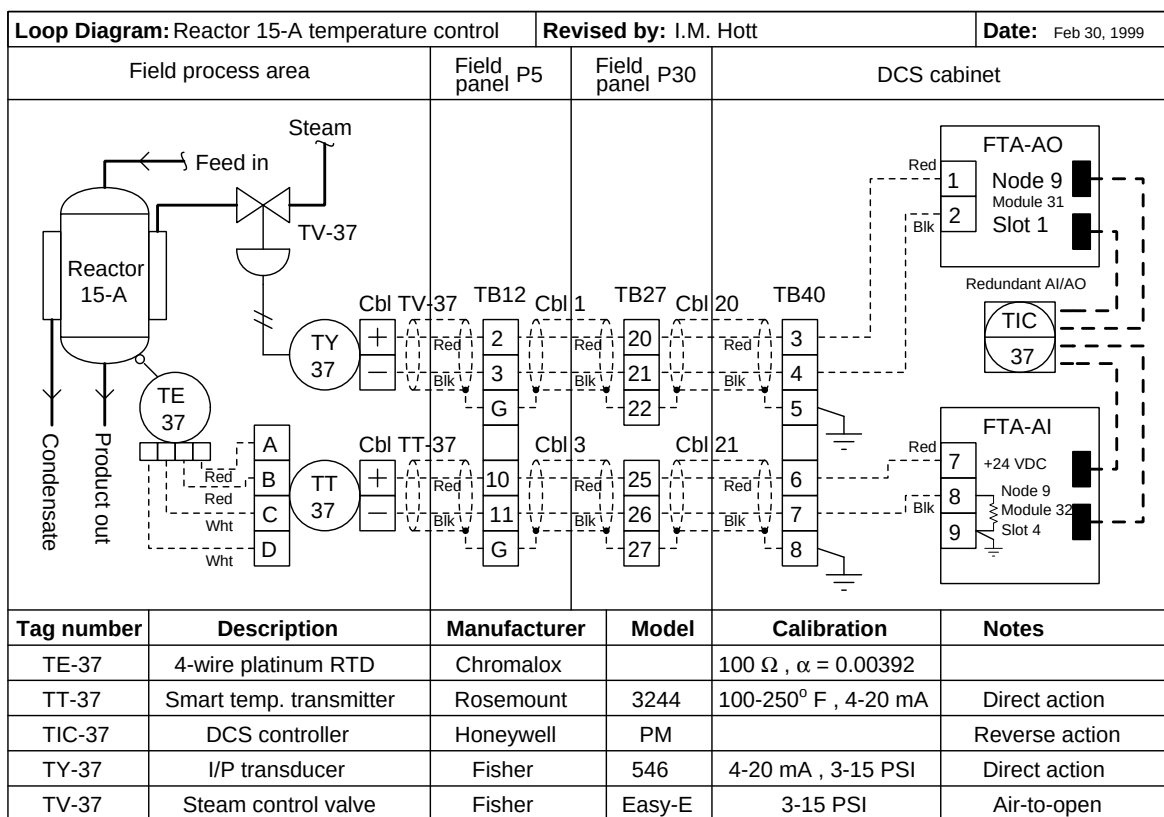
Question 77

Question 78

Question 79

Question 81

Examine this loop diagram for a chemical reactor heating control system, then determine how the system will respond to *any one* of the scenarios listed below (you choose). Your answer should describe four parameters of the control system over time: (1) What happens to the process temperature, (2) What the operator's indication does, (3) Which direction the controller's output changes, and (4) What happens to steam flow through the control valve.



Choose one!

- Broken wire connection at TB12-11
- Short in cable 20
- Resistor fails open in analog input field termination (FTA-AI)
- Sudden influx of *cold* fluid into reactor
- Sudden increase in steam supply pressure and temperature

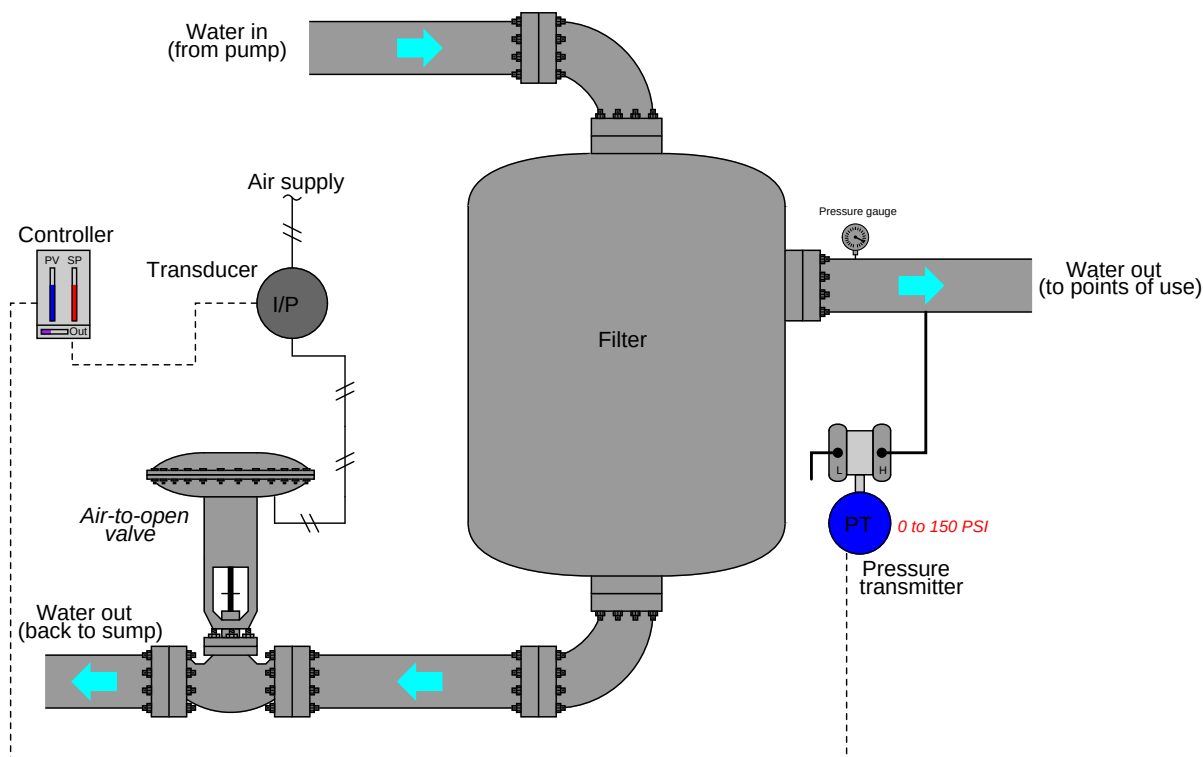
Determine these four system responses:

- Process temperature response over time:
- Operator indication of process temperature over time:
- Controller output over time:
- Steam flow through control valve over time:

file i02450

Question 82

According to the operator, this pressure-control system is not regulating filter water pressure correctly. The controller faceplate indicates the pressure holding at setpoint (110 PSI), but pressure indicated by a pressure gauge on the outlet pipe of the filter shows substantially less pressure (85 PSI):



Your first test is to measure loop current in the circuit connecting the pressure transmitter to the pressure controller. There, your multimeter registers 15.7 milliamps.

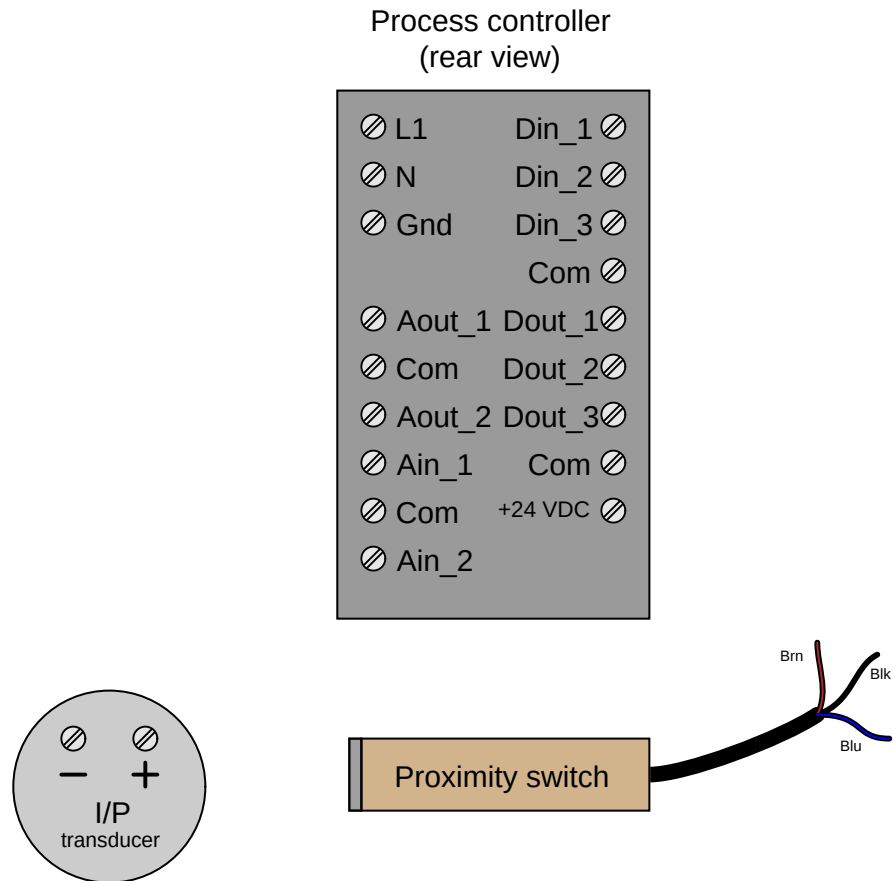
Identify the likelihood of each specified fault for this control system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

Fault	Possible	Impossible
PT out of calibration (outputting wrong current)		
PIC input out of calibration (not interpreting PV signal properly)		
PIC output out of calibration (not sending correct mA signal to I/P)		
Pressure gauge out of calibration (not displaying pressure properly)		
I/P out of calibration (not outputting correct pressure)		
Control valve is oversized		
Control valve is undersized		
PIC is poorly tuned (not making good control "decisions")		
Instrument air supply not at full pressure		

file i03284

Question 83

Sketch the wire connections necessary to interface an electronic (sourcing) proximity switch to (sinking) discrete input channel #2 on the process controller, and also the I/P transducer to analog output #1:



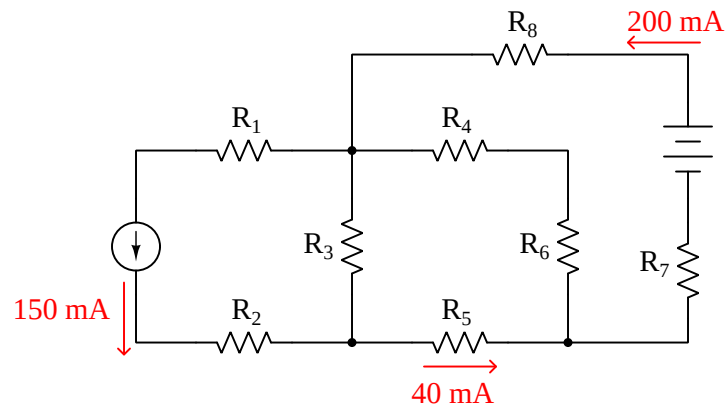
Question 84

Suppose you have recently installed a pressure transmitter ranged from 40 to 240 PSI, complete with a field-mounted analog loop indicator registering 4 to 20 milliamps. The installation is brand-new, and you have not yet received the custom scale for the analog indicator showing 40 to 240 PSI. Instead, the indicator's face simply reads 4 to 20 milliamps.

For the time being, the operators need a way to translate the “milliamp” number value read on the indicator into a “PSI” number value they can relate to the process. Write simple instructions for calculating PSI from any milliamp value they happen to read off this pressure indicator's face.

Question 85

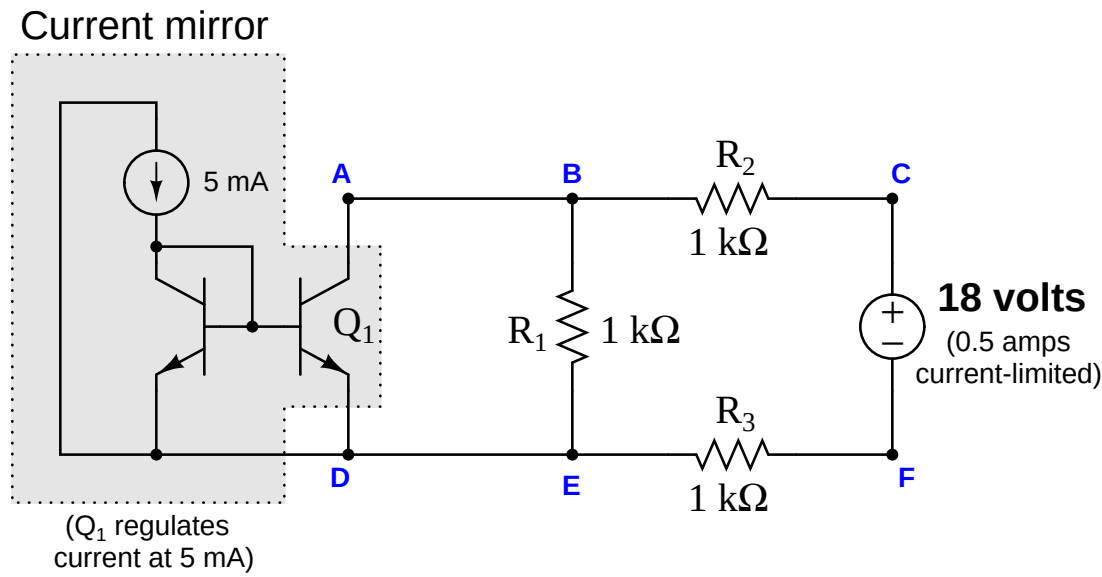
Use Kirchhoff's Current Law to calculate the magnitudes and directions of currents through *all* resistors in this circuit:



Note: all current arrows point in the direction of conventional flow!

Question 86

Suppose a voltmeter connected between test points **D** and **F** registers 5 V in this circuit:

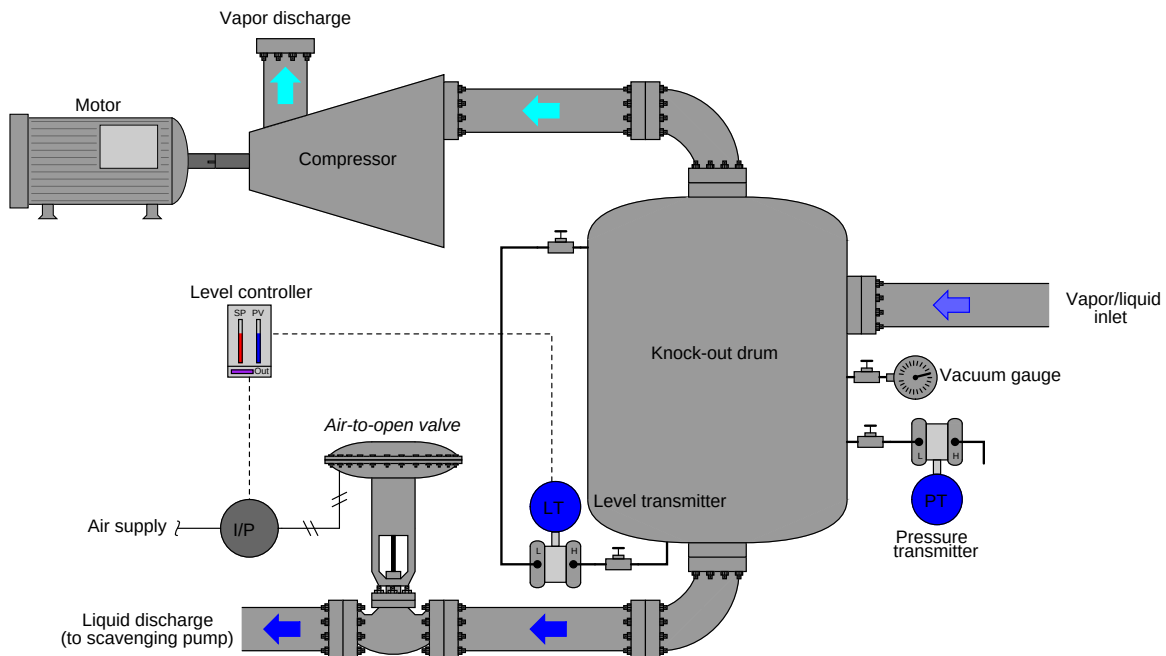


Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

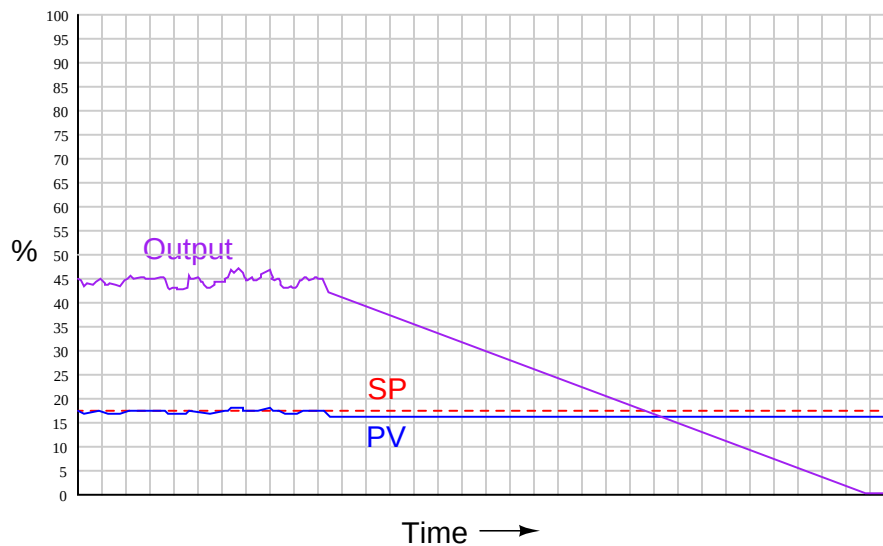
Fault	Possible	Impossible
R_1 failed open		
R_2 failed open		
R_3 failed open		
Q_1 failed open		
R_1 failed shorted		
R_2 failed shorted		
R_3 failed shorted		
Q_1 failed shorted		
Voltage source dead		

Question 87

This level-control system is supposed to maintain a constant liquid level inside the knockout drum, preventing liquid from entering the compressor as well as gas from entering the scavenging pump. Yet, for some reason liquid did manage to enter the compressor, causing the compressor to suffer major damage, and leading to a complete shut-down of the unit:



A trend recording of liquid level and control valve position captured before the explosion holds the only clue as to why this happened. Examine it to see if you can determine the source of the trouble:

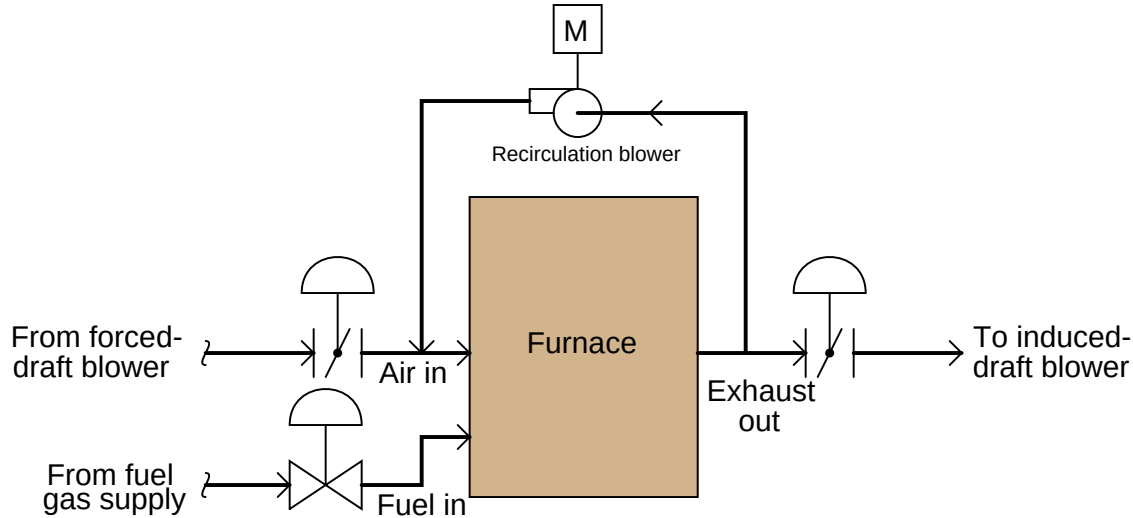


file i02117

Question 88

One of the pollutants generated by high-temperature combustion processes is NO_x : oxides of nitrogen. NO_x forms at high temperatures when nitrogen and oxygen gases in the combustion air combine to form nitrogen-oxygen molecules. These molecules are considered a pollutant because they form nitric acid upon emission to the atmosphere, and they also contribute to the formation of smog.

A common method of mitigating NO_x emissions is to recirculate exhaust gas into the intake of the combustion system. Doing so reduces combustion temperature: a critical variable in the production of NO_x :



The reduction in combustion temperature approximately relates to exhaust gas recirculation by the following formula:

$$X = \frac{T_M - T}{T - T_W}$$

Where,

X = Recirculation fraction (between 0 and 1, unitless)

T_M = Maximum (theoretical) flame temperature

T = Actual flame temperature

T_W = Exhaust gas temperature

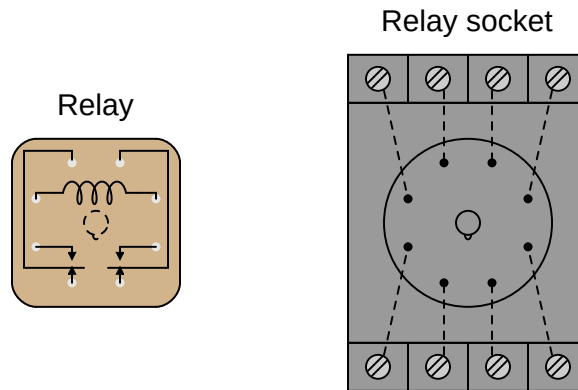
Algebraically manipulate this equation to solve for T , then calculate the actual flame temperature given a maximum theoretical temperature of 3100°F , an exhaust gas temperature of 480°F , and a recirculation factor of 22%.

Also, explain why we must have a recirculation *blower* installed at the location shown in the diagram, rather than a simple recirculation *valve*.

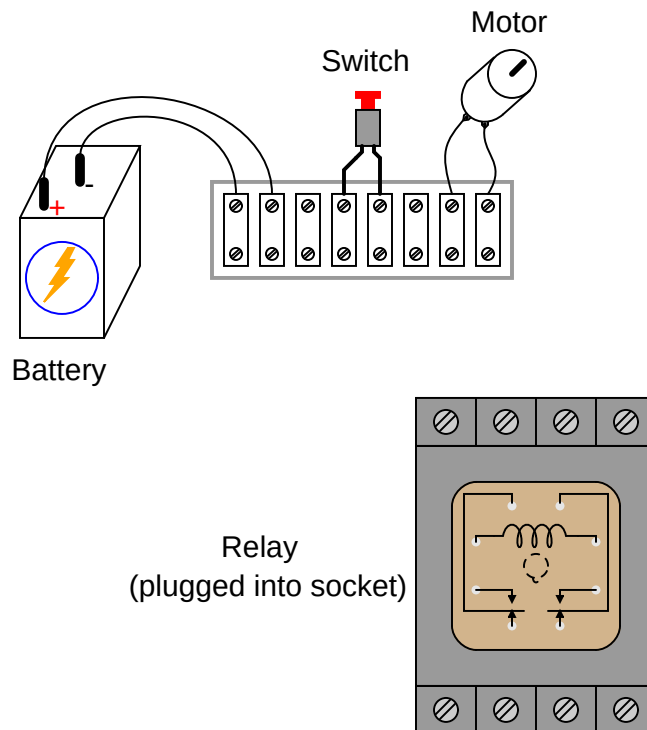
Question 89

Small relays often come packaged in clear, rectangular, plastic cases. These so-called “ice cube” relays have either eight or eleven pins protruding from the bottom, allowing them to be plugged into a special socket for connection with wires in a circuit:

(top views)



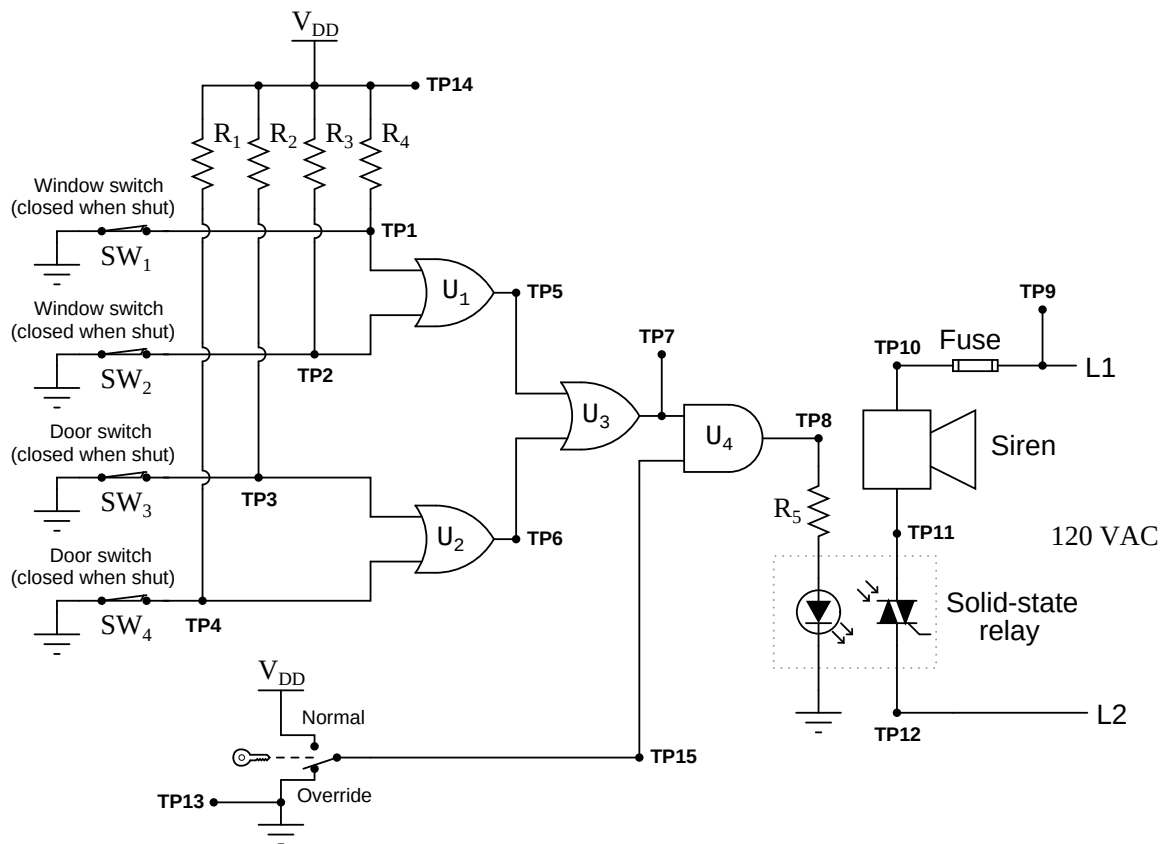
Draw the necessary connecting wires between terminals in this circuit, so that actuating the normally-open pushbutton switch will energize the relay, which will in turn supply electrical power to the motor. The pushbutton switch should not carry any motor current, just enough current to energize the relay coil:



file i03165

Question 90

Something is wrong with this building alarm system circuit. The alarm siren refuses to energize even when all windows and doors are opened:



Using your logic probe, you measure a high signal at TP1, a high signal at TP15, and a low signal at TP8 with all windows and doors propped open, and with the key switch in the “normal” position. From this information, identify two possible faults (either one of which could account for the problem and all measured values in this circuit). Then, choose one of those possible faults and explain why you think it could be to blame. The circuit elements you identify as possibly faulted can be wires, traces, and connections as well as components. Be as specific as you can in your answers, identifying both the circuit element and the type of fault.

- Circuit elements that are possibly faulted
 - 1.
 - 2.
- Explanation of *why* you think one of the above possibilities could be to blame

file i03197

Lab Exercise

Your task is to build, document, and successfully operate a process controlled by a recording PID controller. Several alternative process types exist and are documented in subsequent pages. The working process you build will be used in future lab exercises this quarter to meet other learning objectives, which means you will *not* disassemble this project at the completion of these lab objectives as you normally would.

The following table of objectives show what you and your team must complete within the scheduled time for this lab exercise. Note how some of these objectives are individual, while others are for the team as a whole:

Objective completion table:

Performance objective	Grading	1	2	3	4	Team
Choose process to build	mastery	–	–	–	–	
Team meeting and prototype sketch	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Final loop diagram and system inspection	mastery					– – – –
Process and Instrument Diagram (P&ID)	mastery					– – – –
Trend graph displays PV and Output	mastery	–	–	–	–	
Process exhibits good control behavior	mastery	–	–	–	–	
PV alarm(s) defined and enabled	mastery	–	–	–	–	
Lab question: Instrument connections	proportional					– – – –
Lab question: Commissioning	proportional					– – – –
Lab question: Mental math	proportional					– – – –
Lab question: Diagnostics	proportional					– – – –

The only “proportional” scoring in this activity are the lab questions, which are answered by each student individually. A listing of potential lab questions are shown at the end of this worksheet question. The lab questions are intended to guide your labwork as much as they are intended to measure your comprehension, and as such the instructor may ask these questions of your team day by day, rather than all at once (on a single day).

It is essential that your team plans ahead what to accomplish each day. A short (10 minute) team meeting at the beginning of each lab session is a good way to do this, reviewing what’s already been done, what’s left to do, and what assessments you should be ready for. There is a lot of work involved with building, documenting, and troubleshooting these working instrument systems!

As you and your team work on this system, you will invariably encounter problems. You should always attempt to solve these problems as a team before requesting instructor assistance. If you still require instructor assistance, write your team’s color on the lab whiteboard with a brief description of what you need help on. The instructor will meet with each team in order they appear on the whiteboard to address these problems.

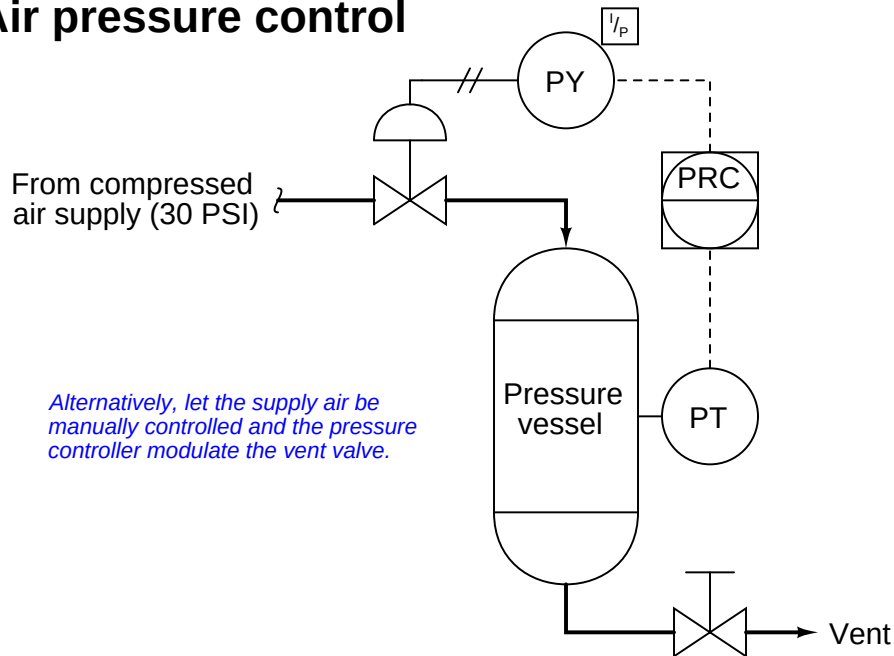
✂----- Cut out tag(s) with scissors, then affix to instrument(s) using transparent tape to show calibration:

CALIBRATED By: _____ Date: _____ Range: _____	CALIBRATED By: _____ Date: _____ Range: _____	CALIBRATED By: _____ Date: _____ Range: _____	CALIBRATED By: _____ Date: _____ Range: _____
--	--	--	--

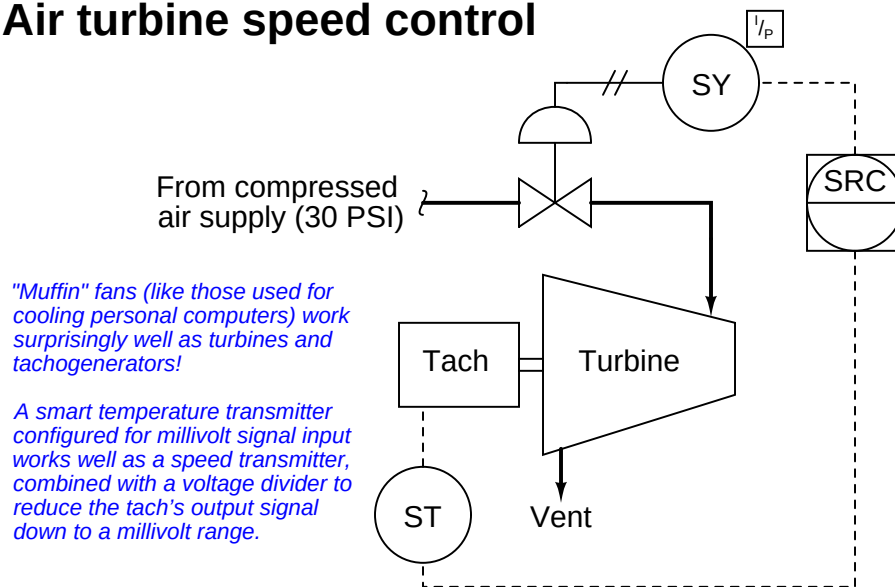
Lab Exercise – choosing a process to build

There are a number of process types to choose from when selecting the one you will build with your team. The only non-negotiable limitations is that the process must be safe, legal, and possible to complete in the time allotted for this lab. What follows are some examples:

Air pressure control



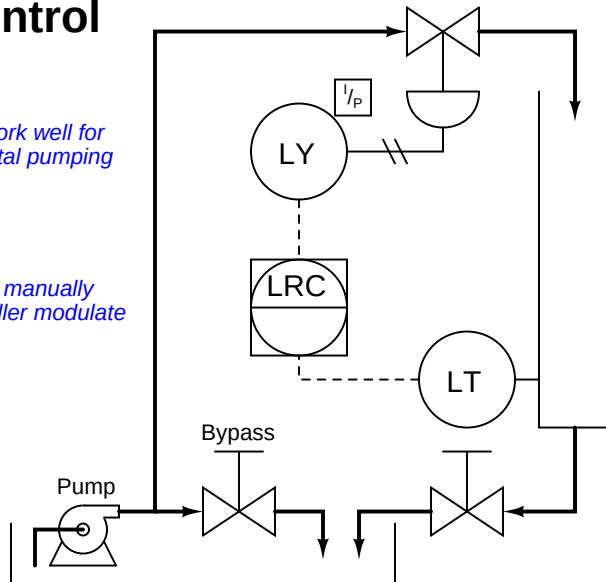
Air turbine speed control



Water level control

Fountain-style water pumps work well for this purpose, so long as the total pumping height (head) is not too great.

Alternatively, let the in-flow be manually controlled and the level controller modulate the drain valve.

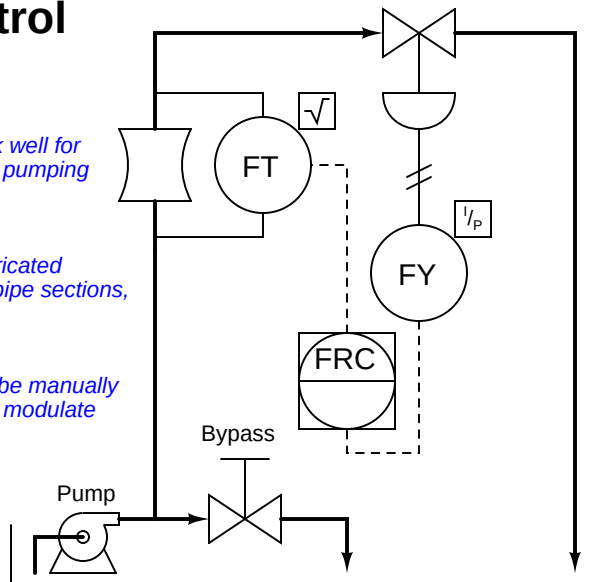


Water flow control

Fountain-style water pumps work well for this purpose, so long as the total pumping height (head) is not too great.

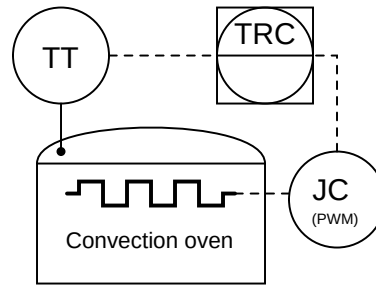
Simple venturi tubes may be fabricated using bell reducers and straight pipe sections, in either plastic or metal.

Alternatively, let the venturi flow be manually controlled and the flow controller modulate the bypass valve.



Oven temperature control

A cheap electric toaster oven or convection oven works well for this purpose. The only "hard-to-find" part is the power controller (JC) which modulates AC power to the heating element in accordance with the temperature controller's 4-20 mA output signal.

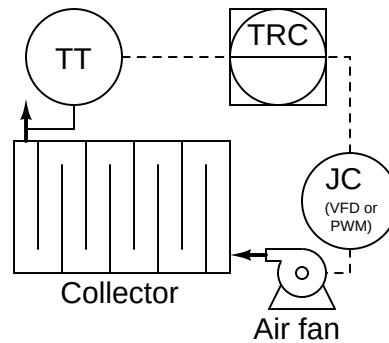


Solar air heater control

For the purposes of this lab exercise, the solar collector may be made out of cardboard with clear plastic food wrap as the cover material.

Paint the inside of the collector flat black for maximum heat absorption capability.

Use a variable-frequency motor drive (VFD) if the fan is turned by an AC motor. If using a DC fan (e.g. computer cooling fan), you may use a simpler PWM power controller.



Other process ideas include:

- Soldering iron temperature control (blowing air over tip with variable-speed fan).
- Draft pressure control (controlling very low air pressure inside of a box).
- Pneumatic piston height control (using lengths of PVC pipe to build a simple piston/cylinder which may be used to lift small weights using modest air pressures). A good way to control air pressure to the piston is to route the I/P transducer's output to a *volume booster* relay and let the relay's output directly drive the piston. Piston height may be sensed using a flexible water tube attached to the piston rod, running to a stationary pressure transmitter.
- Sterno-fired air heat exchanger.
- Miniature steam boiler. *Note: this is an advanced project!*
- Air/Fuel ratio burner control. *Note: this is an advanced project!*
- Servomechanism position control. *Note: this is an advanced project!*
- Inverted pendulum balance. *Note: this is a very advanced project!*

Lab Exercise – team meeting, prototype sketch, and instrument selection

An important first step in completing this lab exercise is to **meet with your instructor** as a team to discuss safety concerns, team performance, and specific roles for team members. If you would like to emphasize exposure to certain equipment (e.g. use a particular type of control system, certain power tools), techniques (e.g. fabrication), or tasks to improve your skill set, this is the time to make requests of your team so that your learning during this project will be maximized.

An absolutely essential step in completing this lab exercise is to work together as a team to **sketch a prototype diagram** showing what you intend to build. This usually takes the form of a simple electrical schematic and/or loop diagram showing all electrical connections between components, as well as any tubing or piping for fluids. This prototype sketch need not be exhaustive in detail, but it does need to show enough detail for the instructor to determine if all components will be correctly connected for their safe function.

For example, if you intend to connect field devices to a PLC (Programmable Logic Controller), your prototype sketch must show how those devices will connect to typical input/output terminals on the PLC, where electrical power will be supplied, etc. Prototype sketches need not show all intermediary connections between components, such as terminal blocks in junction boxes between the field device and the controller.

You should practice good problem-solving techniques when creating your prototype sketch, such as consulting equipment manuals for information on component functions and marking directions of electric current, voltage polarities, and identifying electrical sources/loads. Use this task as an opportunity to strengthen your analytical skills! Remember that you will be challenged in this program to do all of this on your own (during “capstone” assessments), so do not make the mistake of relying on your teammates to figure this out for you – instead, treat this as a problem *you* must solve and compare your results with those of your teammates.

Your team’s prototype sketch is so important that the instructor will demand you provide this plan before any construction on your team’s working system begins. *Any team found constructing their system without a verified plan will be ordered to cease construction and not resume until a prototype plan has been drafted and approved!* Similarly, you should not deviate from the prototype design without instructor approval, to ensure nothing will be done to harm equipment by way of incorrect connections. Each member on the team should have ready access to this plan (ideally possessing their own copy of the plan) throughout the construction process. Prototype design sketching is a skill and a habit you should cultivate in school and take with you in your new career.

When selecting field instruments for this lab exercise, choose a *transmitter* suitable for measuring your process variable, and likely an *I/P converter* used to convert the controller’s 4-20 mA output signal into an air pressure that a control valve may operate on. Electronic process controllers are in several locations throughout the lab, ready to be used for controlling processes. Your instructor will help you select appropriate instruments for the process you have chosen.

You may also need a *data acquisition unit*, or *DAQ* to function as a trend recorder. When used with a personal computer and connected properly to the loop circuit, a DAQ unit will provide graphical displays of loop variables over time. Students usually find the connection of a DAQ unit to their loop controller to be the trickiest part of their loop wiring. You will need to consult the manufacturer documentation on the DAQ unit as well as the field instruments and controller in order to figure out how to wire them together. Even if your process controller already provides trending capability, you may find connection of a DAQ unit to your loop circuits a useful exercise because the ability to quickly connect and use DAQ hardware and software to monitor electrical parameters in a system is a valuable diagnostic skill in this career.

You will find your teammates who have already taken the Measurement course series (INST24X) will be very helpful in showing you how to check, configure, calibrate, and install the measuring instrument(s) you will need for your process!

Planning a functioning system should take no more than an hour if the team is working efficiently, and will save you hours of frustration (and possible component destruction!).

Lab Exercise – circuit design challenge

Your instructor will choose one 4-20 mA field instrument and one control system from the lists shown below, for which you must sketch an accurate circuit diagram showing how the two instruments would connect to each other. If this interconnection between controller and field instrument requires additional electrical components to function (e.g. DC or AC power source, precision 250 Ω resistor, diode, relay, etc.), those must be incorporated into your diagram as well. Instruction manuals for all instrument listed are available on the electronic Instrumentation Reference for your convenience. When your sketch is complete, you must show the relevant manual pages to your instructor for verification of correct connections.

This exercise tests your ability to locate appropriate information in technical manuals and design a correct 4-20 mA analog signal circuit for a given pair of instruments. The electronic Instrumentation Reference will be available to you in order to answer this question.

Since all 4-20 mA “loops” are basically series DC circuits, it is highly recommended that you approach their design the same as for any other DC circuit: carefully identify all *sources* and *loads* in the circuit, trace directions of all currents, and mark the polarities of all voltages. Most of the mistakes made in this type of circuit design challenge may be remedied by careful consideration of these specific circuit-analysis details.

4-20 mA transmitter options

- Pressure
 - Rosemount 1151 Alphaline (analog), 1151 HART, or 3051 HART
 - Yokogawa DPharp EJX110A or EJX910
 - Honeywell ST3000
- Level
 - Rosemount APEX non-contact radar, 3300 GWR, or 5300 GWR
- Temperature
 - Rosemount 444, 644, 3044, or 3144
 - Foxboro RTT15 or RTT30
 - Moore Industries SPT with sourcing (4-wire) 4-20 mA output
 - Moore Industries SPT with sinking (2-wire) 4-20 mA output
 - Moore Industries TRX or TDY
- Flow
 - Foxboro CFT50 coriolis
- Analytical
 - Rosemount 5081-P (pH)
 - Daniel 700 gas chromatograph (4 analog output channels)
 - Foxboro 876PH (pH/ORP/ISE)

Controller options

- Monolithic
 - Siemens 352P
 - Siemens 353
 - Foxboro 716C
 - Foxboro 718TC
 - Foxboro 762CNA
 - Moore Industries 535
 - Honeywell UDC2300
 - Honeywell UDC3500
- Modular – *you choose the appropriate I/O module*
 - Siemens 353R
 - Emerson ROC800 SCADA/RTU
- Distributed Control System (DCS) – *you choose the appropriate I/O module*
 - Emerson DeltaV with M-series I/O
 - Emerson DeltaV with S-series I/O
 - Honeywell Experion with 2MLF series I/O
- Programmable Logic Controller (PLC) – *you choose the appropriate I/O module*
 - Siemens S7-300
 - Rockwell ControlLogix (catalog number 1756)
 - Rockwell CompactLogix (catalog number 1769)

4-20 mA Final Control Element options

- Pneumatic control valve positioners
 - Fisher 3582i positioner
 - Fisher DVC6000 positioner
- Electrically actuated valves (MOV)
 - Limitorque actuator with Modutronic-20 II controller
 - Rotork AQ with Folomatic controller
- AC motor drives (VFD)
 - Rockwell PowerFlex 4
 - Automation Direct GS1

Study reference: the “Analog Electronic Instrumentation” chapter of *Lessons In Industrial Instrumentation*, particularly the section on HART.

Note: a very effective problem-solving strategy for determining how to connect different components together to create a working 4-20 mA current loop is to first identify whether each component acts as a *source* or a *load* in that loop circuit. Then, label voltage polarities (+ , –) and directions of current accordingly. Knowing which way current must flow through each component and which polarity each voltage must have is key to ensuring the inter-component connections are correct.

Lab Exercise – building the system

The Instrumentation lab is set up to facilitate the construction of working instrument “loops,” with over a dozen junction boxes, pre-pulled signal cables, and “racks” set up with 2-inch vertical pipes for mounting instruments. These racks also provide structure for building physical processes, with more than enough weight-bearing capacity to hold any process vessels and equipment. The only wires you should need to install to build a working system are those connecting the field instrument to the nearest junction box, and then small “jumper” cables connecting different pre-installed cables together within intermediate junction boxes.

After getting your prototype sketch approved by the instructor, you are cleared to begin building your system. Instruments attach to 2-inch pipes using special brackets and U-bolts. These brackets and U-bolts are located in the instrument storage area.

Select a specific loop controller for your system. Your instructor may choose the controller for your team, to ensure you learn more than one type of controller during the course of a quarter.

Finally, your process control system needs to have a loop number, so all instruments may be properly labeled. This loop number needs to be unique, so that another team does not label their instruments and cables the same as yours. One way to make your loop number unique is to use the equivalent resistor color-code value for your team’s color in the loop number. For example, if you are the “Red” team, your loop number could be “2”.

Common mistakes:

- Neglecting to consult the manufacturer’s documentation for field instruments (e.g. how to wire them, how to calibrate them).
- Mounting the field instrument(s) in awkward positions, making it difficult to reach connection terminals or to remove covers when installed.
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Failing to tug on each and every wire where it terminates to ensure a mechanically sound connection.
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!

Building a functioning process complete with instrumentation for control typically takes one or two sessions (3 hours each) if all components are readily available and the team is working efficiently!

Lab Exercise – documenting the system

Each student must sketch their own *loop diagram* and their own *P&ID* for their team's system, following proper ISA conventions. The P&ID documents the flow of fluid and materials in your process plus the general control strategy. The loop diagram documents all wiring and tube connections between instruments. Although the two diagrams reinforce one another and might possibly be combined into one, the industry standard is to use two separate diagrams.

Sample loop diagrams are shown in the next question in this worksheet. These loop diagrams must be *comprehensive* and *detailed*, showing every wire connection, every cable, every terminal block, range points, etc. The principle to keep in mind here is to make the loop diagram so complete and unambiguous that anyone can follow it to see what connects to what, even someone unfamiliar with industrial instrumentation. In industry, loops are often constructed by contract personnel with limited understanding of how the system is supposed to function. The loop diagrams they follow must be so complete that they will be able to connect everything properly without necessarily understanding how it is supposed to work.

Every instrument and every signal cable in your loop needs to be properly labeled with an ISA-standard tag number. An easy way to do this is to wrap a short piece of masking tape around each cable (and placed on each instrument) then writing on that masking tape with a permanent marker. Although no industry standard exists for labeling signal cables, a good recommendation is to label each two-wire cable with the tag number of the field instrument it goes to. Thus, every length of two-wire cable in a pressure transmitter circuit should be labeled "PT-*x*" (where "*x*" is the loop number), every flow control valve should be labeled "FV-*x*", etc. Remember that the entire loop is defined by the process variable it measures: if the PV is *temperature* then the transmitter will be a *TT*, the control valve will be a *TV*, the controller will be a *TC*, etc.

When your entire team is finished drafting your individual loop diagrams, call the instructor to do an inspection of the loop. Here, the instructor will have students take turns going through the entire loop, with the other students checking their diagrams for errors and omissions along the way. During this time the instructor will also inspect the quality of the installation, identifying problems such as frayed wires, improperly crimped terminals, poor cable routing, missing labels, lack of wire duct covers, etc. The team must correct all identified errors in order to receive credit for their system.

After successfully passing the inspection, each team member needs to place their loop diagram in the diagram holder located in the middle of the lab behind the main control panel. When it comes time to troubleshoot another team's system, this is where you will go to find a loop diagram for that system!

The P&ID's will be submitted to the instructor for inspection as well, but the process itself need not be inspected again.

Common mistakes:

- Forgetting to label all signal wires (see example loop diagrams).
- Forgetting to label all field instruments with their own tag names (e.g. PT-83).
- Forgetting to note all wire colors.
- Forgetting to put your name on the loop diagram!
- Using non-standard tags for instruments rather than ISA 5.1 standard notation.
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

Creating and inspecting accurate loop diagrams should take no more than one full lab session (3 hours) if the team is working efficiently! Creating and inspecting accurate P&IDs will take more time, but not an entire lab session (3 hours).

Lab Exercise – operating the system

All networked loop controllers in the lab (DCS, DDC, PLC, single-loop networked) provide graphing functionality so that you may plot your process variable (PV) and output values over time. This graphical data is essential for tuning PID-controlled loops. If you happen to be using a controller that does not provide graphing capability, your team must attach a trend recorder and/or a data acquisition unit (plus a personal computer) to the necessary signal cables so that these values are recorded over time.

PID tuning is a subject worthy of its own course, and so you will not be expected to achieve perfect control on your process. You will find, however, that one of the best ways to learn PID tuning is by “playing” with your process as it responds to different tuning parameters entered into the loop controller. The expectation for “good control behavior” in the context of this lab exercise is for the loop to exhibit response that is no less stable following large setpoint changes than the classic “quarter-wave damping” described by Ziegler and Nichols in their 1942 paper.

Most student-built processes are quite safe to operate. However, if your process harbors any unique hazards (e.g. overflowing water may present a slip hazard, overheated oven may cause materials to smoke or burn), you must be aware of these hazards and limit everyone’s exposure to them. All team members for each process must be familiar with the inherent hazards of their process and how to mitigate them. One operational step to help avoid problems is to configure the controller for *setpoint limits* preventing the setpoint value from being placed at “dangerous” values in automatic mode. Just what these setpoint limit values should be set to varies with the process and the team’s experience operating it.

As your time with the process builds, you will no doubt arrive at ideas for improving it. Feel free to work with your team to optimize the process in any way you see fit. The goal is to have your process as robust and “problem-free” as possible for other teams to use it in later coursework!

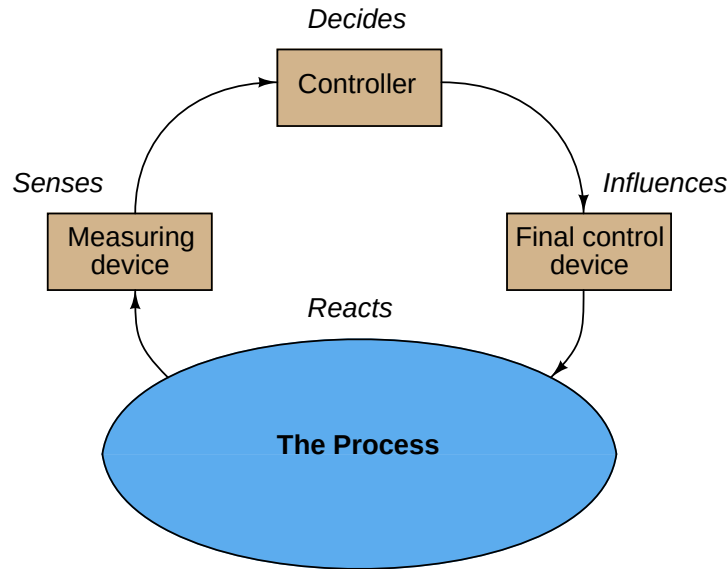
After you have built and tuned your process, you should identify and configure alarm values for the controller’s PV display. Most controllers have PV alarm capability built in, signaling a condition of excessive or insufficient PV if those alarm points are ever tripped. You need to set at least a high alarm on the PV so that when other teams come after you to re-tune your process, they have some “guidepost” showing them what PV value(s) they should not exceed! If your team has enough time, feel free to connect an actual alarm indicator light and/or audible buzzer to your control system that turns on (and latches) if an alarm point is exceeded.

A tendency of students when they first learn to tune PID control loops is to proceed carelessly because they know the “toy” processes they are learning to tune aren’t going to harm anything if their PVs go out of bounds. While this assumption might be true for your team’s process, it is not good to form or reinforce bad habits. Thus, the inclusion of alarm point(s) on your process PV – especially if connected to some form of signaling device that is annoying and/or embarrassing to trip such as a loud buzzer – makes for a better teaching tool for others learning PID tuning!

Troubleshooting PID-controlled processes

It is quite likely during the testing and operation of your control loop that problems will develop. The following advice is given to assist you in your diagnostic efforts, to quickly identify which portion(s) of your control loop might be at fault.

Recall that every feedback control loop consists of four basic elements: an element that *senses* the process variable (e.g. primary sensing element, transmitter), an element that *decides* what how to regulate this process variable (e.g. a PID controller), an element that *influences* the process variable (e.g. a control valve, motor drive, or some other final control device), and finally the process itself which *reacts* to the final control device's actions:



You can check each element of your feedback control loop by comparing its input with its output to see if each element is doing what it should:

- (1) **Decision-making:** Carefully examine the controller faceplate, looking at the values of PV, SP, and Output. Is the controller taking appropriate action to force PV equal to SP? In other words, is the Output signal at a value you would expect if the controller were functioning properly to regulate the process variable at setpoint? If so, then the controller's action and tuning are most likely not at fault. If not, then the problem definitely lies with the controller.
- (2) **Sensing:** Compare the controller's displayed value for PV with the actual process variable value as indicated by local gauges, by feel, or by any other means of detection. If there is good correspondence between the controller's PV display and the real process variable, then there probably isn't anything wrong with the measurement portion of the control loop (e.g. transmitter, impulse lines, PV signal wiring, analog input of controller, etc.). If the displayed PV disagrees with the actual process variable value, then something is definitely wrong here.
- (3) **Influencing:** Compare the controller's displayed value for Output with the actual status of the final control element. If there is good correspondence between the controller's Output display and the FCE's status, then there probably isn't anything wrong with the output portion of the control loop (e.g. FCE, output signal wiring, analog output of controller, etc.). If the controller Output value differs from the FCE's state, then something is definitely wrong here.
- (4) **Reacting:** Compare the process variable value with the final control element's state. Is the process doing what you would expect it to? If so, the problem is most likely not within the process (e.g. manual valves, relief valves, pumps, compressors, motors, and other process equipment). If, however, the process is not reacting the way you would expect it to given the final control element's state, then something is definitely awry with the process itself.

A crude closed-loop PID tuning procedure

Tuning a PID controller is something of an art, and can be quite daunting to the novice. What follows is a primitive (oversimplified for some situations!) procedure you can apply to many processes.

Step 1

Understand the process you are trying to control. If you do not have a fundamental grasp on the nature of the process you're controlling, it is pointless – even dangerous – to change controller settings. Here is a simple checklist to cover before touching the controller:

- What is the process variable and how is it measured?
- What is the final control element, and how does it exert control over the process variable?
- What safety hazards exist in this process related to control (e.g. danger of explosion, solidification, production of dangerous byproducts, etc.)?
- How far am I allowed to “bump” the process while I tune the controller and monitor the response?
- How is the controller mode switched to “manual,” just in case I need to take over control?
- In the event of a dangerous condition caused by the controller, how do you shut the process down?

Step 2

Understand what the settings on the controller do. Is your controller configured for gain or proportional band? Minutes per repeat or repeats per minute? Does it use reset windup limits? Does rate respond to error or PV alone? You had better understand what the PID values do to the controller's action if you are going to decide which way (and how much) to adjust them! Back in the days of analog electronic and pneumatic controllers, I would recommend to technicians that they draw little arrow symbols next to each adjustment knob showing which way to turn for more aggressive action – this way they wouldn't get mixed up figuring out gain vs PB, rep/min vs min/rep, etc.: all they had to think of is “more” or “less” of each action.

Step 3

Manually “bump” the manipulated variable (final control element) to learn how the process responds. In manual mode, *you* are the controller! What you need to do is adjust the process to learn how it responds: is it an integrating process, a self-regulating process, or a runaway process? Is there significant dead time or hysteresis? Is the response linear and consistent? Many process control problems are caused by factors other than the controller, and this “manual test” step is a key diagnostic technique for assessing these other factors.

Step 4

Set the PID constants to “minimal” settings and switch to automatic mode. This means gain less than 1, no integral action (0 rep/min or maximum min/rep), no derivative action, and no filtering (i.e. damping).

Step 5

“Bump” the setpoint and watch the controller's response. This tests the controller's ability to manage the process on its own. What you want is a response that is reasonably fast without overshooting or undershooting too much, and without undue cycling. The nature of the process and the constraints of quality standards will dictate what is “too much” response time, over/undershoot, and cycling.

Step 6

Increase or decrease the control action aggressiveness according to the results of Step 5.

Step 7

Repeat steps 5 and 6 for P, I, and D, one at a time, in that order. In other words, tune the controller first to act as a P-only controller, then add integral (PI control), then derivative (PID), each as needed.

Step 8

“Bump” a load in the process and watch the controller’s response. This tests the controller’s ability to manage variations in process load over time. A controller’s response to load changes will often differ from its response to setpoint changes. You still want controller response that is reasonably fast without overshooting or undershooting too much, and without undue cycling. However, you may have to find some compromise in tuning between good setpoint response and good load response. How you decide that compromise depends on whether the controller really needs to respond mostly to setpoint changes (e.g. the slave controller of a cascade loop) or to load changes.

Step 9

Increase or decrease the control action aggressiveness according to the results of Step 8.

Step 10

Repeat steps 8 and 9 for P, I, and D, one at a time, in that order. In other words, tune the controller first to act as a P-only controller, then add integral (PI control), then derivative (PID), each as needed.

Caveats

The procedure described here is *very* crude, and should only be applied as a student’s first foray into PID tuning, on a safe “demonstration” process. It assumes that the process responds predominantly to proportional (P-only) action, which may not be true for some processes. It also gives no specific advice for tuning based on the results of step 3, which is the mark of an experienced PID tuner. With study, practice, and time, you will learn what types of processes respond best to P, I, and D actions, and then you will be able to intelligently choose what parameters to adjust, and what closed-loop behaviors to look for.

Lab questions

- **Instrument connections**

- Determine correct wire connections between instruments to create a working 4-20 mA loop circuit, based on diagrams of instruments with terminals labeled
- Correctly determine all electrical sources and loads, as well as all voltage polarities and current directions in a 4-20 mA loop circuit, based on diagrams of instruments with terminals labeled

- **Commissioning and Documentation**

- Identify and explain the distinction between *direct* and *reverse* control modes in the loop controller
- Identify some of the main *loads* in your process, and explain how they may be varied while the process is running
- Describe how to connect a loop calibrator to measure current output by a loop-powered (2-wire) transmitter
- Describe how to connect a loop calibrator to measure current output by a controller
- Describe how to connect a loop calibrator to simulate current coming from a loop-powered (2-wire) transmitter
- Describe how to connect a loop calibrator to simulate current coming from a self-powered (4-wire) transmitter
- Describe how to connect a loop calibrator to stroke a control valve

- **Mental math** (no calculator allowed!)

- Convert a proportional band value into a gain value, or vice-versa
- Convert a repeats/(minute or second) integral value into a (minutes or seconds)/repeat integral value, or vice-versa
- Calculate the pneumatic pressure in a 3-15 PSI range corresponding to x percent.
- Calculate the electrical current in a 4-20 mA range corresponding to x percent.
- Calculate the electrical voltage in a 1-5 volt range corresponding to x percent.
- Calculate the percentage value of a pneumatic pressure signal x PSI in a 3-15 PSI range.
- Calculate the percentage value of an electrical current signal x mA in a 4-20 mA range.
- Calculate the percentage value of an electrical voltage signal x volts in a 1-5 volt range.

- **Diagnostics**

- Explain how to distinguish an “open” cable fault from a “shorted” cable fault using only a voltmeter (no current or resistance measurement, but assuming you are able to break the circuit to perform the test)
- Explain how to use the “manual” mode of a process controller as a diagnostic test to check for problems in a control system
- Determine whether or not a given diagnostic test will provide useful information, given a set of symptoms exhibited by a failed system
- Identify at least two plausible faults given the results of a diagnostic test and a set of symptoms exhibited by a failed system
- Propose a diagnostic test for troubleshooting a failed system and then explain the meanings of two different test results

[file i01558](#)

The Rules of Fault Club

- (1) Don't try to find the fault by looking for it – perform diagnostic tests instead
- (2) *Don't try to find the fault by looking for it – perform diagnostic tests instead!*
- (3) The troubleshooting is over when you have correctly identified the nature and location of the fault
- (4) It's just you and the fault – don't ask for help until you have exhausted your resources
- (5) Assume one fault at a time, unless the data proves otherwise
- (6) No new components allowed – replacing suspected bad components with new is a waste of time and money
- (7) We will practice as many times as we have to until you master this
- (8) Troubleshooting is not a spectator sport: you have to troubleshoot!

These rules are guaranteed to help you become a better troubleshooter, and will be consistently emphasized by your instructor.

Loop Diagram:				Revised by:		Date:
Tag #	Description	Manufacturer	Model	Input range	Output range	Notes

Loop diagram requirements

Perhaps the most important rule to follow when drafting a loop diagram is *your diagram should be complete and detailed enough that even someone who is not an instrument technician could understand where every wire and tube should connect in the system!*

- **Instrument “bubbles”**

- Proper symbols and designations used for all instruments.
- All instrument “bubbles” properly labeled (letter codes and loop numbers).
- All instrument “bubbles” marked with the proper lines (solid line, dashed line, single line, double lines, no lines).
- *Optional:* Calibration ranges and action arrows written next to each bubble.

- **Text descriptions**

- Each instrument documented below (tag number, description, etc.).
- Calibration (input and output ranges) given for each instrument, as applicable.

- **Connection points**

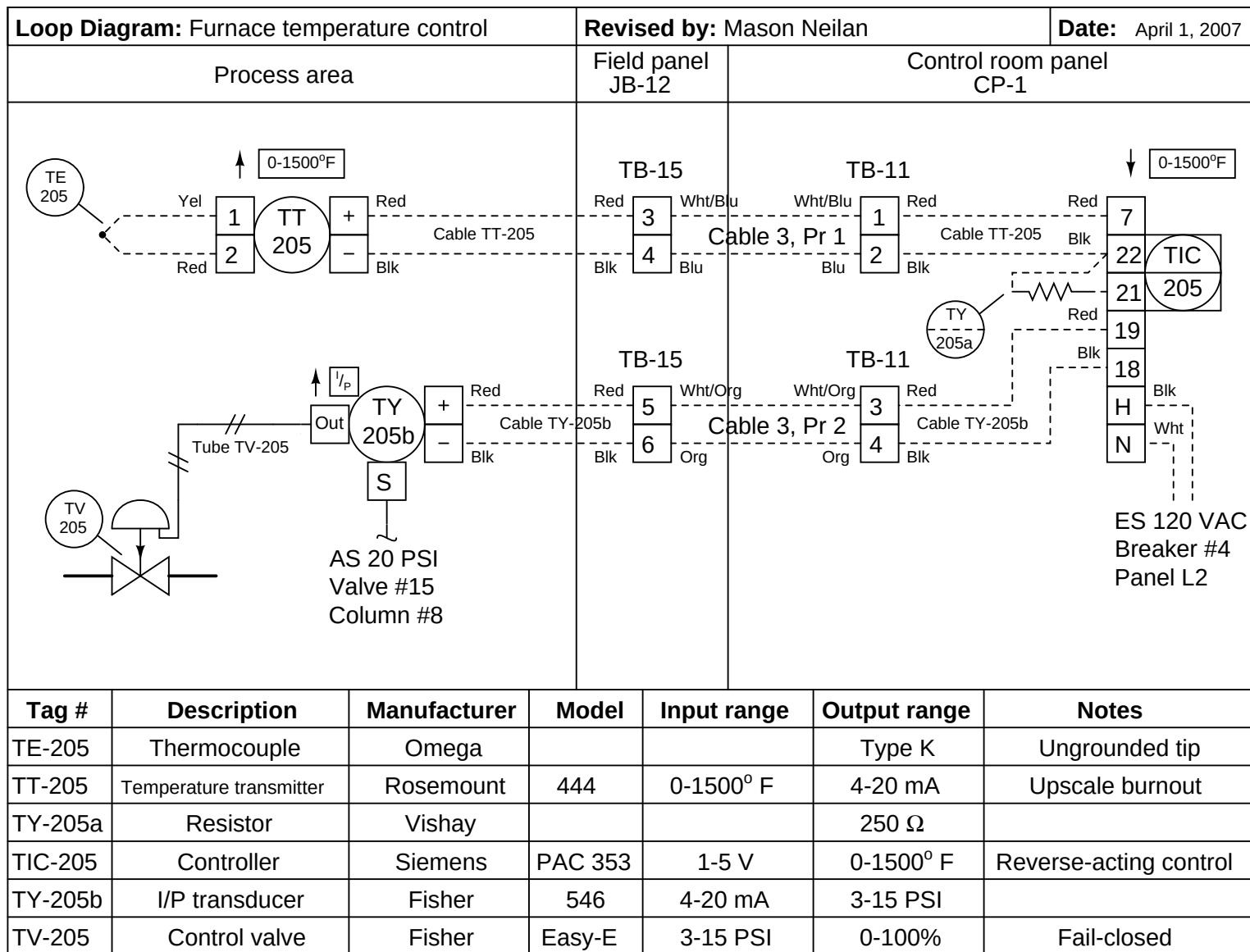
- All terminals and tube junctions properly labeled.
- All terminal blocks properly labeled.
- All junction (“field”) boxes shown as distinct sections of the loop diagram, and properly labeled.
- All control panels shown as distinct sections of the loop diagram, and properly labeled.
- All wire colors shown next to each terminal.
- All terminals on instruments labeled as they appear on the instrument (so that anyone reading the diagram will know which instrument terminal each wire goes to).

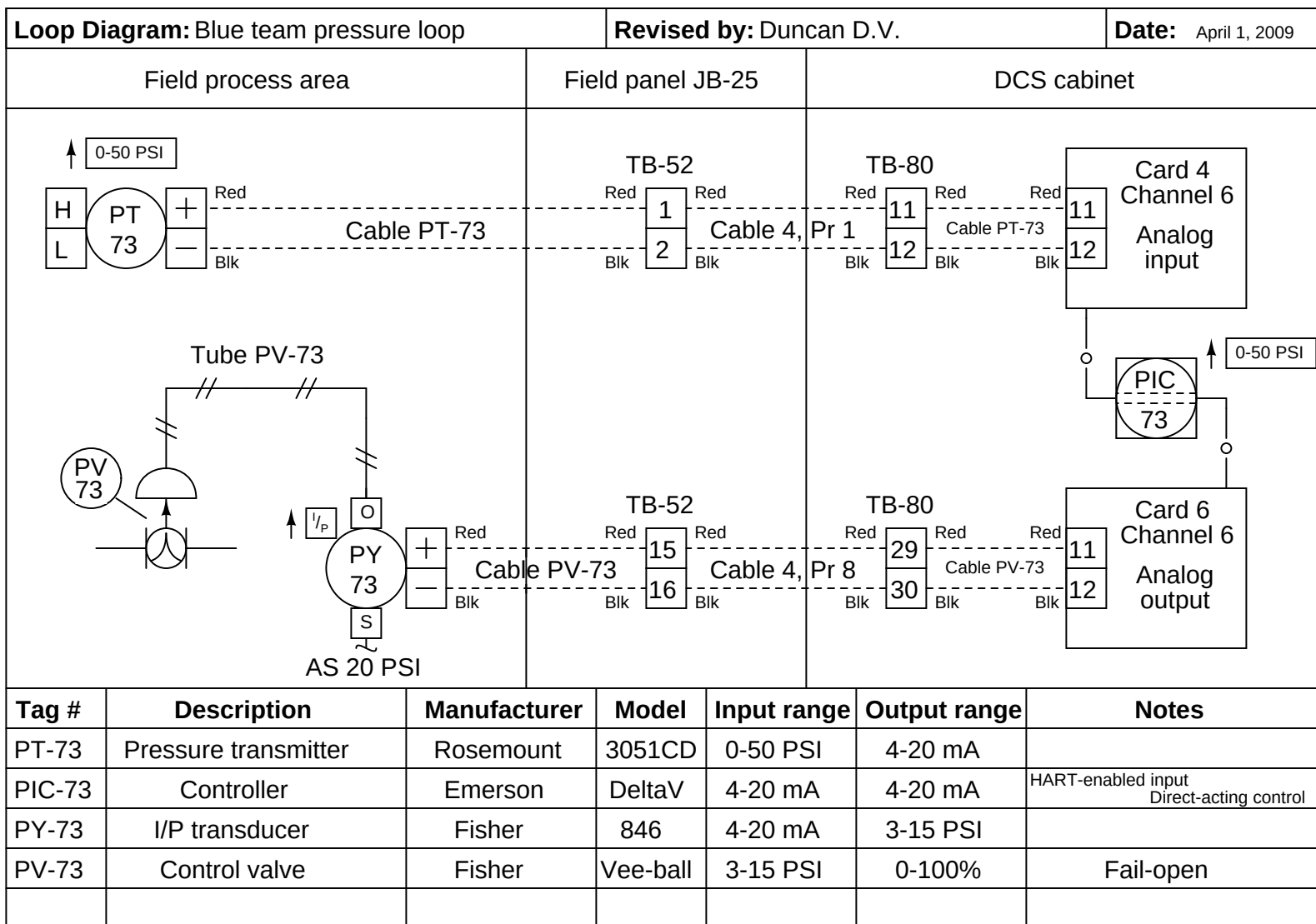
- **Cables and tubes**

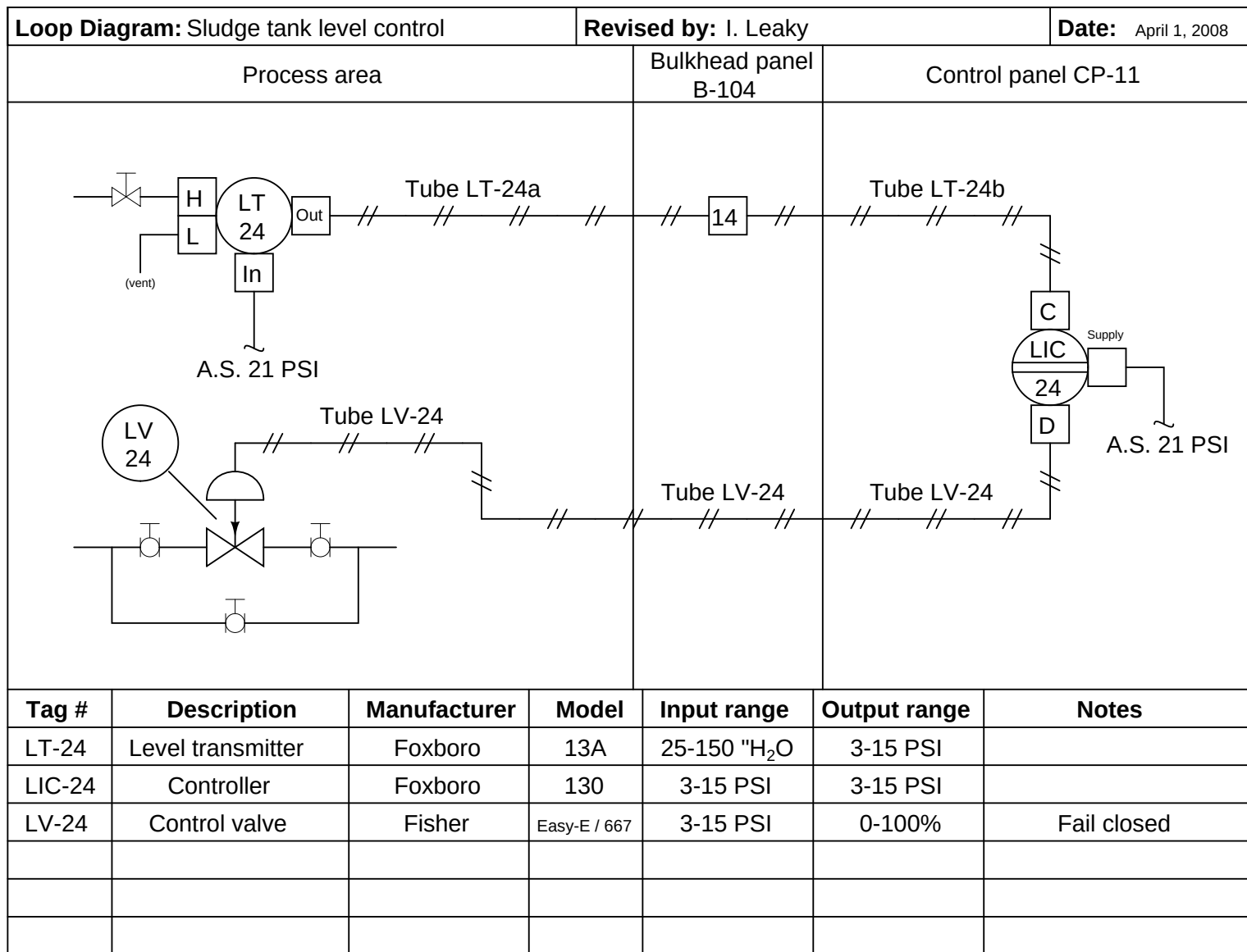
- Single-pair cables or pneumatic tubes going to individual instruments should be labeled with the field instrument tag number (e.g. “TT-8” or “TY-12”)
- Multi-pair cables or pneumatic tube bundles going between junction boxes and/or panels need to have unique numbers (e.g. “Cable 10”) as well as numbers for each pair (e.g. “Pair 1,” “Pair 2,” etc.).

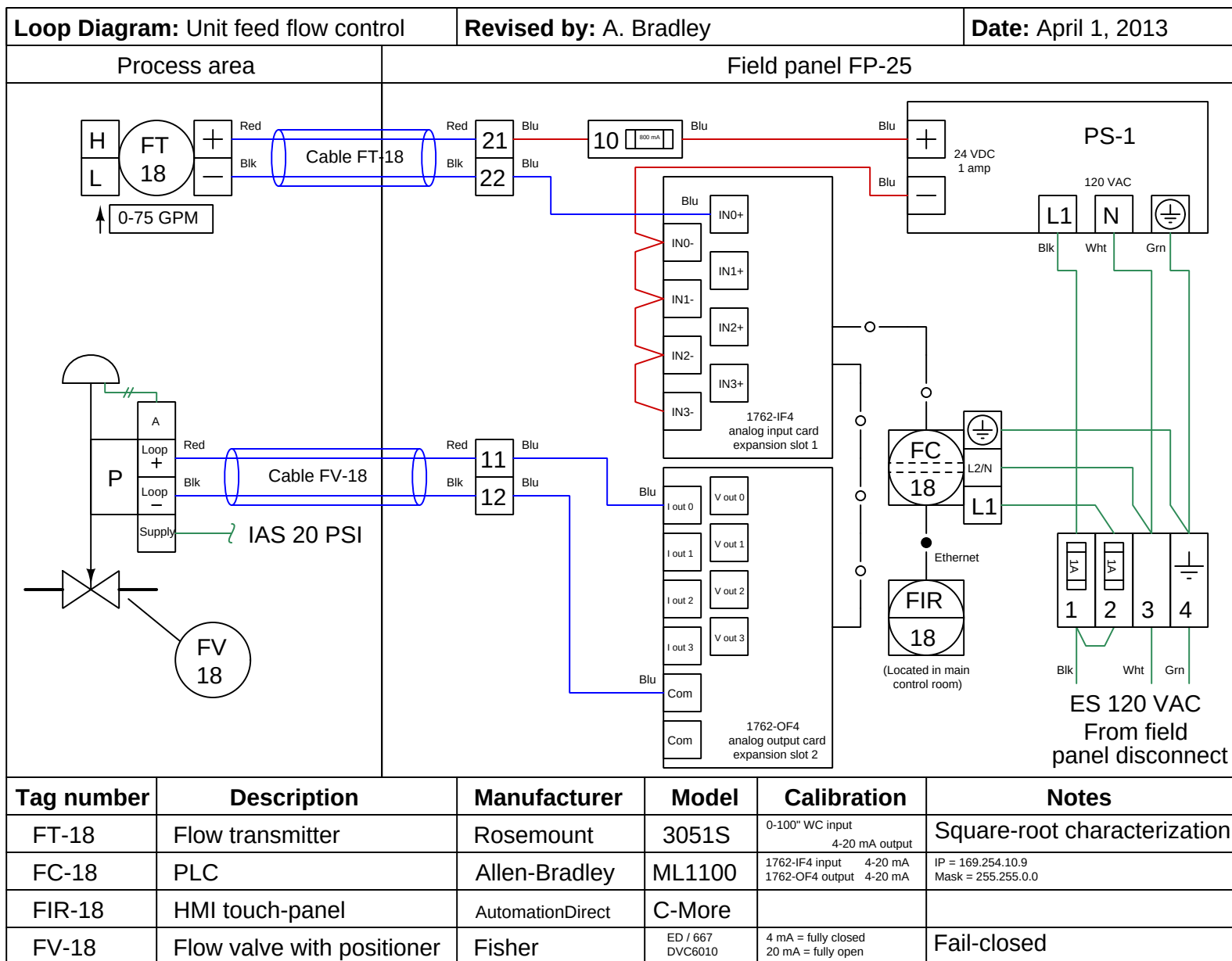
- **Energy sources**

- All power source intensities labeled (e.g. “24 VDC,” “120 VAC,” “20 PSI”)
- All shutoff points labeled (e.g. “Breaker #5,” “Valve #7”)









Answers

Answer 1

Answer 2

Answer 3

Answer 4

A *load* is any variable in a process (besides the manipulated variable) that has influence over the process variable being controlled.

Note: the following answers are not exhaustive. In other words, there may be more loads than what is listed here for each process!

- Example 1: ambient air temperature
- Example 2: incoming flow rate
- Example 3: upstream and downstream pressures
- Example 4: steam flow rate, steam temperature

Answer 5

Partial answer:

- Controller #1 needs to be *reverse-acting*
- Controller #3 needs to be *direct-acting*
- Controller #5 needs to be *direct-acting* (i.e. PV input is “+” and SP input is “−”)
- Controller #7 needs to be *reverse-acting* (i.e. PV input is “−” and SP input is “+”)

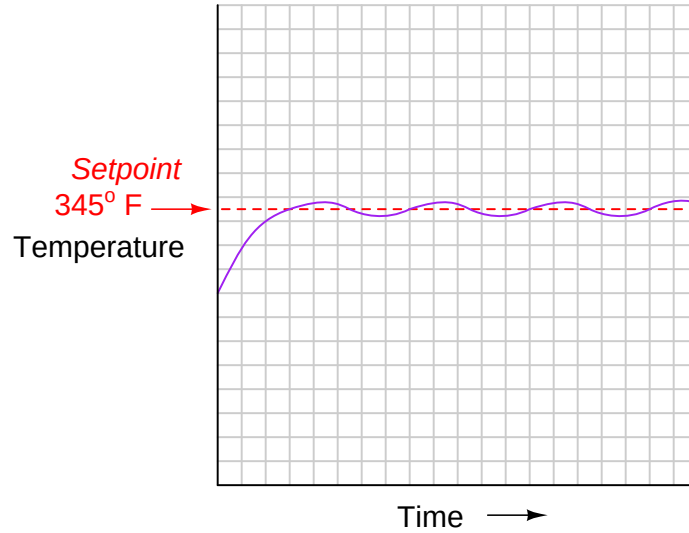
Answer 6

Answer 7

Answer 8

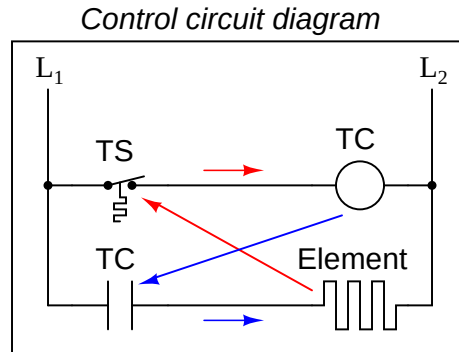
One potential cause is digester R-101 running too cold, cooling off the contents of the second digester.

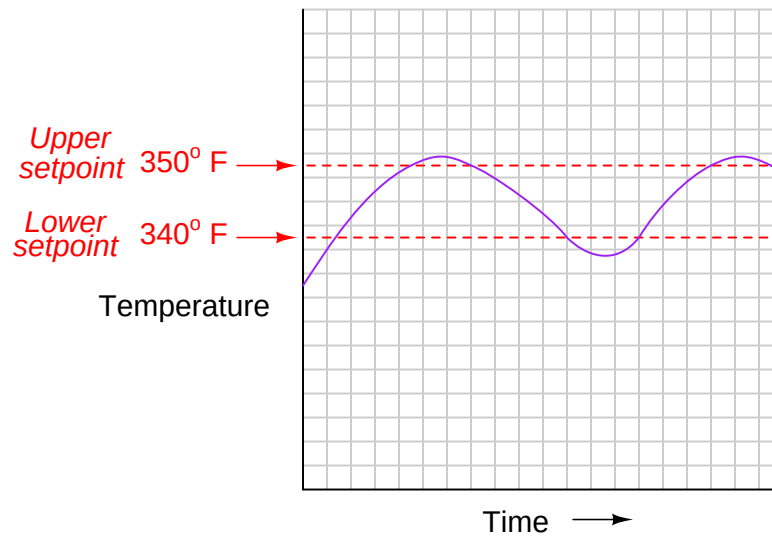
A simple *on-off* control system will apply full power to the heating element if the temperature is less than the setpoint, and will completely shut off power to the heating element if the temperature is greater than the setpoint. The result is a temperature graph that oscillates around the setpoint value over time.



As you can see, the temperature can never settle at any one temperature, since the control action is all-or-nothing, and changes based on a simple “greater-than” or “less-than” relationship between the process variable and the setpoint.

This is an example of a *closed-loop* control system. The control “loop” may be represented in the ladder logic schematic by means of causal arrows:





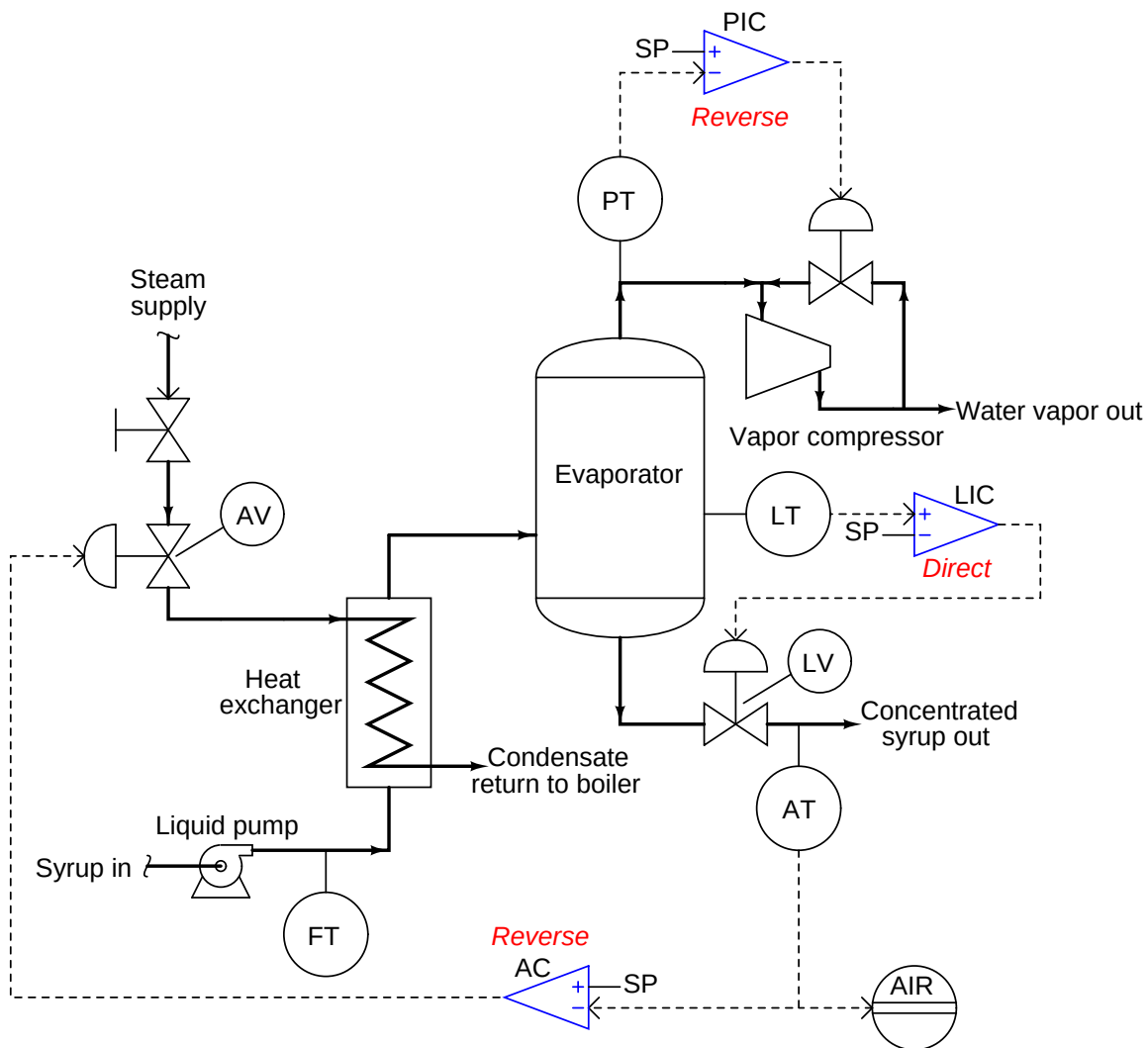
Answer 11

The human operator plays the part of a *reverse-acting* controller, because the valve action must be opposite of any changes in process variable. For example, if the water temperature increases, then the operator should move the control valve further closed.

- PV = water temperature
- SP = ideal (target) water temperature, in operator's mind
- MV = Fuel gas control valve position

Answer 12

The syrup's sugar concentration will eventually become *excessive* as the analytical controller (AC) attempts to maintain setpoint.

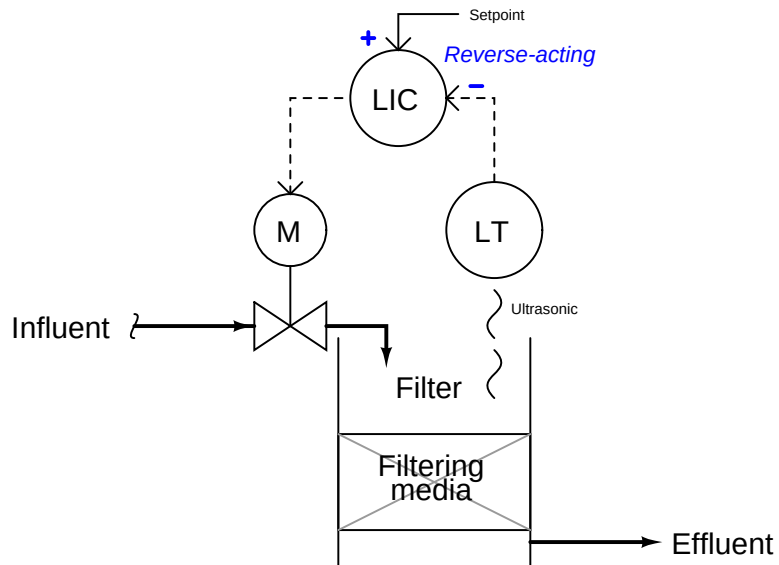


The analytical controller (AC) is reverse-acting in order to close off the steam valve if the sugar concentration of the syrup increases.

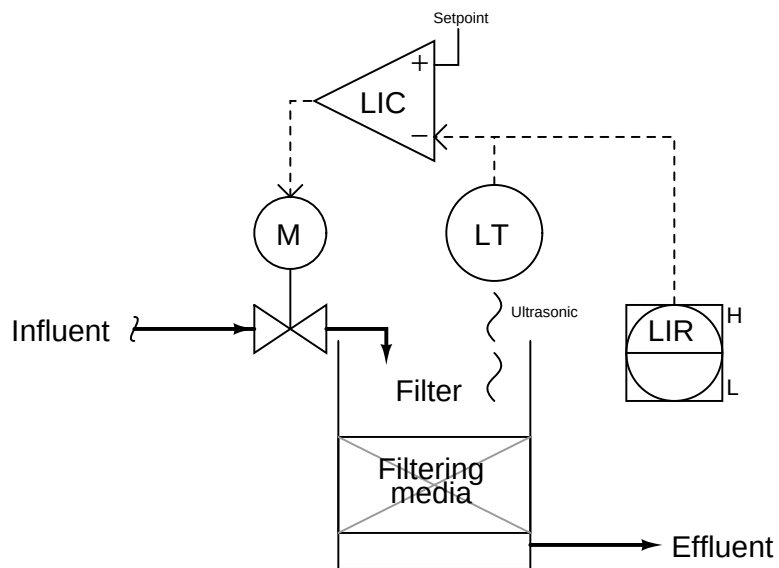
The level indicating controller (LIC) is direct-acting in order to open up the discharge valve if the evaporator level increases.

The pressure indicating controller (PIC) is reverse-acting in order to open up the compressor recycle valve if the pressure inside the evaporator decreases (i.e. if the vacuum becomes too strong).

This controller needs to be *reverse-acting*:



This re-drawing of the control system uses an opamp symbol in place of the ISA-standard circle used to represent a loop controller:



- A sudden increase in effluent flow rate (clean water demand): *controller output increases*
- Level transmitter fails high (indicating 100% full water level): *controller output decreases*
- Control valve actuator fails, driving valve fully open (ignoring controller signal): *controller output decreases*

Answer 15

One possible fault has to do with the control valve: perhaps something has happened to make it fail closed (loss of air supply, signal, etc.). Other possible problems include the following:

- Pump not running (no source of fluid power to motivate flow)
- Very poor controller tuning
- Wrong controller action
- Valve failed closed (loss of air supply, signal, etc.)
- Transmitter failed, showing no flow when in fact there is

A good “first test” for troubleshooting the loop is to check the controller output: is it trying to open up the valve?

Answer 16

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

Answer 26

Answer 27

Answer 28

The “automatic” mode is proper, and the low output signal value tells us the controller is doing all it can to bring the temperature down. The problem, therefore, is *not* in the controller’s automatic response!

- Example 1: increasing temperature, operator should close the valve more
- Example 2: increasing level, operator should open the valve more
- Example 3: increasing flow, operator should close the valve more
- Example 4: increasing temperature, operator should open the valve more

The goal with these questions is to think like an operator, in order to have a clear understanding of the process's needs. Only when one recognizes the required direction of valve operation to correct for an upset (off-setpoint) condition is it possible to properly and confidently configure an automatic controller to do the same. This is something every instrument professional needs to consider when designing and/or commissioning a control system: *which way does the final control element need to go, in order to stabilize the process variable if it deviates too high?*

In the first example, we would need to move the fuel gas valve further closed (toward the shutoff position) if ever the temperature got too high.

In the second example, we would need to move the drain valve further open to correct for a too-high liquid level in the vessel.

In the third example, we would need to move the flow control valve further closed (toward shutoff) if ever the flow rate measured too high.

In the fourth example, we would need to open the control valve further in order to reduce a too-high oil temperature exiting the heat exchanger. The rationale for this direction of valve motion is to increase the flow rate of the oil so that each molecule spends less time in the heat exchanger absorbing heat from steam and increasing in temperature.

Answer 30

Gain = 0.5 and bias = 30%

Answer 31

- “Displ” button = *change display mode*
- “Auto/Man” button = *toggle between automatic and manual modes*
- “Config” button = *Enter the configuration menu*

- “Up” (↑) Button = *increase setpoint*
- “Down” (↓) Button = *decrease setpoint*
- “Left” (←) Button = *decrease output*
- “Right” (→) Button = *increase output*

An operator might wish to manually control a process in the event that the transmitter providing the process variable (PV) signal fails.

Answer 32

One of the better simulations I've found is from *Dex Automation*. You can run the free Java application streaming on the website or you can pay a small fee for a stand-alone executable to run offline.

Answer 33

When a controller is in the automatic mode, output tracking means the manual output value follows along (“tracks”) the automatic output value so that when the controller is switched to manual mode, the transition will be bumpless.

When a controller is in the manual mode, setpoint tracking means the setpoint value follows along (“tracks”) the process variable value so that when the controller is switched to automatic mode, the setpoint will begin at the same value as the process variable, and control starts with no error.

In other words, setpoint tracking means the controller assumes the process is where you want it to be at the moment you switch to automatic mode.

Answer 34

Answer 35

Answer 36

Answer 37

Answer 38

Answer 39

Answer 40

Answer 41

Answer 42

Answer 43

Answer 44

Partial answer:

- If a wire breaks loose at TB56-4, creating an “open” fault in the loop circuit, determine what will happen at the alarm unit (AAH, AAL-41) and also where you would expect to measure voltage in the loop circuit and where you would expect to measure *no* voltage in the loop circuit. *The AAL would trip (but not the AAH), and we would expect to measure voltage between the wires of cable 52 but not between the wires of cable 30.*
- If a fire breaks out near the conduit through which cable 52 runs, causing the conductors inside cable 52 to *short* together, what will happen in this system? Where would you expect to measure voltage in the loop circuit, and where would you expect to measure *no* voltage in the loop circuit? Where would you expect to measure current in the loop circuit, and where would you expect to measure *no* current in the loop circuit? *The AAL would trip (but not the AAH), and we would expect to measure no voltage anywhere in the loop circuit. However, we would still have current at the terminals of the AIT-41 transmitter (although no current to the right of the short).*

Answer 45

Answer 46

Answer 47
Answer 48
Answer 49
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Answer 51
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Answer 53
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Answer 57
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Answer 78

Answer 79

Answer 80

Answer 81

This is a graded question – no answers or hints given!

Answer 82

This is a graded question – no answers or hints given!

Answer 83

This is a graded question – no answers or hints given!

Answer 84

This is a graded question – no answers or hints given!

Answer 85

This is a graded question – no answers or hints given!

Answer 86

This is a graded question – no answers or hints given!

Answer 87

This is a graded question – no answers or hints given!

Answer 88

This is a graded question – no answers or hints given!

Answer 89

This is a graded question – no answers or hints given!

Answer 90

This is a graded question – no answers or hints given!

Answer 91

Answer 92

Your loop diagram will be validated when the instructor inspects the loop with you and the rest of your team.